ADOPTING SUSTAINABLE WASTE MANAGEMENT PRACTICES IN SELECTED HOUSEHOLD WASTES WITH GREEN ENERGY APPROACH VIA LIFE CYCLE ASSESSMENT

by

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B.Sc. in Environmental Engineering, Middle East Technical University, 2020

Submitted to the Institute of Environmental Sciences
in partial fulfillment of the requirements for the degree of
Master of Science
in
Environmental Technology

Boğaziçi University
2024

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DATE OF APPROVAL: 17/04/2024

ACKNOWLEDGEMENTS

The journey to complete my study was a profound and rewarding experience and I owe my deepest gratitude to the many individuals and institutions whose support and encouragement enabled me to do so.

First, I would like to express my heartfelt gratitude to my supervisor, Prof. Dr. Nilgün Kıran Cılız. Her unwavering guidance and expertise have been the cornerstone of this endeavor. Her mentoring and encouragement, from the beginning of the research idea to the last stages of thesis writing, were invaluable.

For their valuable feedback, constructive criticism, and encouragement throughout this process, I am indebted to my jury members, Prof. Dr. Fatoş Germirli Babuna and Assistant Prof. İrem Daloğlu Çetinkaya. Their expertise and academic guidance have contributed significantly to the sophistication and depth of this work.

My deepest gratitude goes to my family; my mother Gülşen Fanosçu, who would be extremely proud and happy if she could have witnessed the entire story of my success up close. I am endlessly thankful to my beloved brother Oğuz Barın for his unwavering support, understanding, encouragement, thoughtfulness and unexpected cheering surprises that he has made despite living 8 thousand km away; from a different time zone. I am most grateful to my friend, my sister, and my roommate Ece Öğüten for being there all the time, being among the top-supporters and not losing her patience at our 4:00 am kitchen working sessions. I especially would like to express my sincerest to the dearest lady Ceyda Kalıpçıoğlu who walks along by my side on this journey and shares every feeling and emotion with all her heart and brain without a matter. I'm also very lucky to have my friends from college and work; my colleagues who kept encouraging, understanding, and providing me with occasional respite during difficult times. Throughout the journey, their love and belief in me have been my source of strength.

In closing, I would like to express my heartfelt thanks to each person who has played a role, no matter how big or small, in this journey. Their support and encouragement were my motivation to complete this study.

ABSTRACT

ADOPTING SUSTAINABLE WASTE MANAGEMENT PRACTICES IN SELECTED HOUSEHOLD WASTES WITH GREEN ENERGY APPROACH VIA LIFE CYCLE ASSESSMENT

Over decades, humankind has become more responsible for depletion of Natural Resources (NR) and disturbing the ecological balance of Earth's systems due to rising population and excess amount of industrialization practices. The demand for NR has increased, which leads to call for action on Sustainable Consumption and Production (SCP) patterns globally. In this manner, sustainability and green growth practices in daily short-term and long-term consumer goods as well as sustainable end-of-life practices should be promoted. In this study, food, paper, packaging; and household e-waste (electrical and electronic equipment) are analyzed with the Life Cycle Assessment (LCA) methodology. Sustainable Waste Management (WM) is targeted; mainly focusing on efficiency in recycling rates as proposed in European Union Waste Framework Directive (EU WFD), aiming transition to greener economy. Environmental impacts arising from recycling these wastes are analyzed by conducting LCA studies for a typical family's daily household activities. Different recycling rates of waste products are presented in the light of Turkey's National Energy Plan, and Turkey's Decarbonization Roadmap within the EU Circular Economy Action Plan perspective. The proposed strategies are integrated into the study by comparing the country's electricity generation profile in 2020 with the proposed electricity generation shares of 2030, 2035 and 2050 scenarios as well as EU's recycling rate targets. The results which also consider increased public awareness on recycling clearly revealed that, by developing sustainable public behaviour, in addition to increased recycling efficiency, the increased share of using renewable energy in the recycling equipment significantly reduces the studied environmental impacts.

ÖZET

SEÇİLMİŞ EVSEL ATIKLARDA SÜRDÜRÜLEBİLİR ATIK YÖNETİMİ UYGULAMALARININ YEŞİL ENERJİ YAKLAŞIMI VE YAŞAM DÖNGÜSÜ DEĞERLENDİRMESİ İLE BENİMSENMESİ

Çağlar boyunca, insanlık artan nüfus ve aşırı endüstrileşme uygulamalarının bir sonucu olarak doğal kaynakların tükenmesi ve ekolojik dengenin bozulması konusunda giderek daha sorumlu hale gelmiştir. Fosil yakıt ve doğal kaynaklara olan talebin önemli ölçüde artması küresel Sürdürülebilir Tüketim ve Üretim (STÜ) modellerine yönelik bir aksiyon alınması ihtiyacını doğurmaktadır. Bu bağlamda, günlük kısa ömürlü ve uzun ömürlü tüketici ürünlerinde sürdürülebilirlik ve yeşil büyüme uygulamalarının teşvik edilmesi gerekmektedir. Bu çalışmada, gıda, kağıt ve ambalaj gibi günlük kısa ömürlü tüketim ürünleri ile, evsel e-atık (elektrikli ve elektronik ekipman) gibi uzun ömürlü endüstriyel ürünler; atık yönetimi kategorisi altında Avrupa Birliği Atık Yönetimi Yönetmeliği kapsamında öncelikle geri dönüşüm verimliliğine odaklanarak Yaşam Döngüsü Değerlendirmesi (YDD) yöntemiyle analiz edilmekte ve çalışmanın bütününde yeşil ekonomiye geçişin önemini vurgulamak amaçlanmaktadır. Atık ürünlerin geri dönüşümünde hedeflenen farklı verim yüzdeleri, hem Türkiye'nin Ulusal Enerji Planı hem de AB Döngüsel Ekonomi Eylem Planı perspektifinde Türkiye'nin 2050'de Net Sıfır Yol Haritasına yönelik aksiyonlari hedefleyerek ele alınmaktadır. Tüketici ürünleri atıklarının geri dönüşümünden kaynaklanan çevresel etkiler, geri dönüşüm çerçevesinde, tipik bir ailenin günlük ürettiği evsel atıklar için YDD çalışmaları yapılarak derinlemesine analiz edilmiştir. Geri dönüşümde kullanılan elektrik dağılımı Türkiye'nin 2020 elektrik üretim profili ile, önerilen 2030, 2035 ve 2050 senaryolarının elektrik üretim payları karşılaştırılarak çalışmaya entegre edilmiştir. Çalışma ile önerilen 2030, 2035 ve 2050 senaryoları, halkın geri dönüşüm alanındaki farkındalığının arttığını da göz önüne alarak hedeflenen geri dönüşüm verimine ulaşıldığını varsaymıştır. Buna göre atık yönetiminde gelişen farkındalıkla birlikte, tüketilen elektrikte yenilenebilir enerji payı artışının söz konusu çevresel etkileri önemli ölçüde azalttığı açıkça ortaya konulmaktadır.

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LIST OF SYMBOLS/ABBREVIATIONS

Abbreviation	Explanation
AD	Anaerobic Digestion
ADP	Abiotic Depletion Potential
AGİD	Aydınlatma Gereçleri İmalatçıları Derneği
CBAM	Carbon Border Adjustment Mechanism
CE	Circular Economy
CSR	Corporate Social Responsibility
DPP	Digital Product Passport
DRS	Deposit Refund Scheme/System
EEE	Electrical and Electronic Equipment
ELDAY	Elektrikli ve Elektronik Geri Dönüşüm ve Atık Yönetim Derneği
EoL	End of Life
EPS	Extended Producer Responsibility
ETS	Emission Trading System
EU	European Union
FAO	Food and Agriculture Organization
FLW	Food Loss Waste
FSC	Food Supply Chain
FW	Food Waste
GHG	Greenhouse Gas
GPP	Green Product/Public Procurement
GWP	Global Warming Potential
HTP	Human Toxicity Potential
LCA	Life Cycle Assessment
MAETP	Marine Aquatic Ecotoxicity Potential
MSW	Municipal Solid Waste
OECD	Organization for Economic Cooperation and Development
OFMSW	Organic Fraction of Municipal Solid Waste
PET	Polyethylene Terephthalate

POCP	Photochemical Ozone Creation Potential
PPI	Pulp and Paper Industry
PPWD	Packaging and Packaging Waste Directive
RE	Resource Efficiency
REDD+	Reducing Emissions from Deforestation and Forest Degradation
RoHS	Restriction of Hazardous Substances
SCP	Sustainable Consumption and Production
SFO	Sustainable Forest Operations
SWM	Solid Waste Management
TÜBİSAD	Türkiye Bilişim Sanayicileri Derneği
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
WEEE	Waste Electrical and Electronic Equipment
WFP	World Food Program
WFD	Waste Framework Directive
WM	Waste Management
WTE	Waste to Energy

1. INTRODUCTION

It is stated by the United Nations Environment Program (UNEP) that due to increased demand of products and services globally, the rates of resource extraction have been rising. Greater economic potential connected to improved material and energy efficiency is promised by slower and closed material cycles which adapt the principle of green transformation (Singh, et al. 2019). Numerous alternatives are being proposed and implied to achieve green transformation. Yet, uncertainties and challenges still exist in how to deal with the outcomes of these overconsumptions. One specific outcome would be the increased amount of waste production globally. Increasing urbanization and industrialization are driving the growth of global municipal waste, by 2050, it is expected that 68% of the world's population will live in urban areas. This increasing waste generation is putting pressure on municipal solid waste management systems. If not properly managed, this waste threatens human health and the environment (Knickmeyer, 2020).

Among the 17 sustainable development goals of the United Nations, the one related with ensuring Responsible Consumption and Production - SDG 12 is analyzed in this study by covering a great number of methodologies implied globally, the national and international regulations followed, the initiatives and actions related with Circular Economy (CE) perspective and environmental impacts of consumer goods category. Apart from relevant SDGs, the concept of Sustainable Consumption and Production (SCP) is confronted in the concept of CE by implementing the information of 10 R-Imperatives, which attempt to reduce resource use through modified manufacturing applications (e.g., remanufacture and recycle materials) and consumption practices (e.g., reject reduce and resell/reuse) (Suski al. 2021).

As stated in the European Green Deal (2019), Europe aims to reduce the continent`s greenhouse gas emissions by 55% with a target year of 2030 and become the world’s first climate-neutral continent by 2050 with proposed in Fit for 55 Package. In this manner several mechanisms and policy standards have been introduced such as the European Green Deal Investment Plan and Just Transition Mechanism. The EU has developed the Mechanism to help communities and industries transition to a low-carbon economy in an equitable manner and introduced it on January 14th, 2019. It includes a dedicated fund of €7.5 billion from the EU budget, along with up to €45 billion in additional funding from the InvestEU program. These funds will support the regions and sectors most affected by the transition, helping them to adapt and prosper in a more environmentally friendly future. In addition,

further financial support for this transition will be provided by a public lending facility of €25-30 billion, backed by the European Investment Bank and the EU budget (European Commission[1]).Following such improvements, European Climate Law was released in March 4th, 2020, New Industrial Strategy for Europe and Circular Economy Action Plan have also been introduced to clearly set the rules. By European Climate Law, the continent's target of net zero greenhouse gas emissions has become legally binding. In addition, by adapting the EU's New Industrial Strategy that was disclosed on March 10th, 2020, it is aimed to ensure the long-term competitiveness of European industry while putting sustainability and innovation at the forefront. It highlights the importance of transitioning to cleaner energy sources and reducing carbon emissions, and outlines plans for Europe to achieve climate neutrality by 2050. Recognizing the importance of digital technologies in driving economic growth and fostering innovation across industries, the strategy also focuses on shaping Europe's digital future (European Commission[2]). In addition to those, Europe also proposed the New European Bauhaus Initiative on May 17th, 2021. The New European Bauhaus Initiative integrates a cultural and creative perspective into the European Green Deal, demonstrating how sustainable innovation can enrich our daily lives. By focusing on sectors like construction and textiles, it seeks to accelerate the transition towards circular and low-carbon products, ensuring broader access to eco-friendly alternatives for all citizens (European Union, 2023).

The New Circular Economy Action Plan that is presented in March 2020 promotes sustainable products and empowers consumers within the European Union. It encourages eco-friendly design and resource efficiency to create a more circular and sustainable economy, empowering consumers to make environmentally friendly choices. The Action Plan is based on the following main set of actions, which are evaluated in a detailed way throughout the study; the EU's bold Sustainable Product Policy, rolling out in three phases, aims to revolutionize product design, empower consumers, and drive circularity across key value chains like packaging, electronics and ICT, construction and buildings, batteries, vehicles, plastics, food and textiles. From widening the Ecodesign Directive to proposing mandatory recyclable content and waste reduction measures, the plan tackles hazardous substances, promotes reusables, and builds a robust market for secondary resources, all while minimizing waste and maximizing value within the EU's borders. It's a comprehensive shift towards a greener, more sustainable future for European products and consumption (European Parliament, 2023).

Along with the Circular Economy approach, while implementing Sustainable Consumption and Production practices, the fact that low recycling rates of wastes and excess fossil fuel usage over renewables results in devastating environmental impacts, lead to take action on increasing the

treatment efficiency by not disturbing the natural and finite resources more. To alleviate the possible outcomes, the concepts of energy, resource and material consumption patterns are analyzed from both manufacturer and consumer sides. In this context, sustainable practices are likely to be developed by adopting strategies like Green Public Procurement (GPP), Eco-design & Eco-labelling, Digital Product Passport (DPP), Extender Producer Responsibility (EPS) and Deposit Refund Schemes (DRS) that are covered under EU targets. Such concepts are directly related with the field of life cycle assessment - end of pipe treatment - recycling techniques of relevant household goods, revealing the fact that instead of increased shares of fossil fuels for electricity generation, better use of renewables gives more promising results for a better world and better future with increased efficiencies in recycling.

This study focuses on comparing the environmental impacts of recycling efficiency in the wastes of different consumer goods by integrating Turkey's Energy Plans that propose target shares of renewable energy sources in the overall electricity generation.

A status analysis is conducted and current regulatory principles around the world are evaluated within SCP patterns in daily short-term consumables as food, paper, and packaging; and long-term industrial products like household e-waste (electrical and electronical equipment) in the recycling context.

2. LITERATURE REVIEW

2.1. Sustainable Consumption and Production

The scientific community became aware that unsustainable development was causing economic and environmental destruction in 1970s. The considerations on SCP plans have risen to remarkable levels and become significant therefore, the matters of SCP and current climate change issues have been discussed in numerous conferences internationally (Wang et al. 2019).

Regarding the call for action, EU Strategy on Climate Change Adaptation, EU Zero Pollution Action Plan and Fit for 55 Package adopted in 2021, focus on air, water and soil quality by aiming reductions in the amount of greenhouse gas emissions, resources water, energy and plastics consumption priorly. In the light of the EU Zero Pollution Action Plan, it is aimed to improve water quality through the reduction in wastes, marine plastic litter (by 50%), and microplastics (by 30%) and soil quality through the reduction in food loss and chemical pesticide use (by 50%). In addition, it targets a 25% reduction in air pollution in EU ecosystems where biodiversity is threatened and a 30% reduction in the number of people chronically affected by traffic noise. In addition, the plan aims to significantly reduce waste generation, with a specific target of a 50% reduction in municipal waste. Through these measures, the EU aims to enhance the quality of the environment and health and well-being of its citizens (European Commission[3], 2023). Apart from these objectives, the Background Study “In preparation of the Turkish SCP National Action Plan and Roadmap (2020)” and 2022 National Energy Plan of Turkey are among the drivers of the need to urgently adopt sustainable practices in every aspect of life.

As cited in Jonkutė & Staniškis, (2016), to carry out the concept of SCP in daily short-term consumables and long-term industrial products sectors in our country, a sustainable industrial development model throughout the manufacturing sector is required. The techniques and measures of such model should include resource efficiency (RE) and cleaner production (CP) applied to manufacturing processes; Life Cycle Assessment (LCA), eco-design, eco-labeling and environmental product declarations (EPD) exercised on goods or services and corporate social responsibility (CSR).

Through several agreements, including the Paris Agreement and the UN 2030 agenda, the importance of a long-term green transition to combat global warming is highlighted. The green transition has now become crucial in global supply chains and as a result, European Parliament and The Council have adopted so called Emissions Trading System (ETS) by realizing its ETS Directive in 2003 which is a strong keystone of the EU's climate change combat policy. Apart but similar to ETS, under the package of Fit for 55, Carbon Border Adjustment Mechanism (CBAM) has also been introduced, yet not fully implemented by EU (Jonkutė& Staniškis,, 2016).

Both ETS and CBAM focus on carbon-intensive sectors - accounting for about 25% of total CO_2 emissions globally (UNECE, 2021) - such as iron and steel, electricity, aluminum, and fertilizer, chemicals all of which have a high potential for carbon leakage and emit excessive amounts of carbon. (EU ETS, 2022) The Carbon Border Adjustment Mechanism (CBAM) to be implemented during the transitional period from 2023 to 2025 for specific sectors such as cement, iron and steel, electricity, aluminum and fertilizers, all of which are at high risk of carbon leakage and emit significant amounts of carbon. Under this mechanism, imports from countries with lower environmental standards than the EU will be subject to a tax relying on products' carbon content, ensuring a level playing field and providing an incentive to reduce emissions worldwide (European Commission[4], 2023).

In fact, a draft study managed and financed by the World Bank, implemented with three separate components by the Ministry of Industry and Technology (MoIT), the Small and Medium Enterprises Development Organization of Türkiye (KOSGEB) and the Scientific and Technical Research Council of Türkiye (TÜBİTAK) named Türkiye Green Industry Project (2023), highlights the importance of "Engagement Activities for Green Growth Technology Roadmap". The draft SEP work is prepared under the light of EU Green Deal Action Plan and states how the tasks will be carried out that are related with Target 2.2. Reinforcement of technological infrastructure for green transformation, especially "Action 2.2.1. Determination of the prominent technologies that will support compliance with the EU Green Deal and green production through technology needs analysis and carrying out studies for the development, dissemination, and transfer of the identified technologies" of the study. Similarly, the carbon-intensive sectors covered in the draft study are iron-steel, aluminum, chemicals, plastics, cement, and fertilizer (TÜBİTAK, 2023).

Following a recent analysis named "Our World in Data" (2020), almost 73.2% of greenhouse gas emissions result from energy consumption, which is mostly driven by the manufacturing sector(Panagiotopoulou et al. 2021). For example, International Energy Agency (IEA) asserted that

the manufacturing sector is solely accountable for releasing roughly 38% of the world's CO_2 emissions and for consuming nearly one-third of the world's energy (Kannan,. et al. 2022) .

Apart from energy and emissions, water consumption in the manufacturing sector is also significant and it holds almost 20% of the world's overall water consumption that is also expected to increase by 20% to 30% by 2050 (PRB, 2022). According to a recent study, if properly implemented, CE techniques and green growth strategy might reduce global greenhouse gas (GHG) emissions by more than a third while reducing resource consumption by more than a quarter (Kannan, et al. 2022).

The energy consumption of a typical family's activities; among the areas of consuming daily short-term goods such as food, paper, and packaging, and long-term industrial products such as household e-waste (cell phones, dishwasher, refrigerator, etc.) should be further analyzed in terms of differing value chains with differing end of life operations. Such requirement results from electricity consumption being a crucial concept, since it creates several aspects to analyze energy and resource-efficient applications and further develop studies in a beneficial environmental impact manner. According to the UNEP, the burning of fossil fuels is responsible for around 65% of worldwide GHG emissions, with the extraction and processing of metals accounting for about 10% of those emissions(Azadi et al. 2020).

Decarbonization in carbon-intensive industries through rapid development and investment in cleaner, low-carbon goods, and efficient technologies are essential (Cabernard et al. 2019). In place of natural gas or coal, the use of wind, solar photovoltaics and hydropower remarkably decreases the amount of GHG emissions (IEA, 2021). All potential environmental loads for a service such as emissions to air, water, soil, etc. are eventually categorized by the LCA studies based on how much they contribute to various environmental consequences, such as the potential for ozone depletion, global warming, and human toxicity.

SCP is among the key components of decarbonization and transition to a greener economy. A growing number of people prefer to buy green products, such as organic food, energy-efficient electronics, and eco-friendly detergents. Demographic factors such as nationality, gender, age, education level, and income significantly influence preferences for green products (Almulhim & Abubakar, 2021).

In order to improve the efficiency of waste management practices, there is a growing need to raise awareness and provide clear guidance. The benefits of sustainable consumption practices are increasingly recognized, despite challenges such as inconvenience and lack of knowledge. One of the key challenges in moving to a CE model is raising awareness and changing behavior (Smol et al. 2018). In this context, the importance of integrating sustainable production and consumption principles into everyday routines is crucial for long-term sustainability. Consumer behavior in selecting products and services plays a critical role in the implementation of a CE model (Almulhim & Abubakar, 2021).

2.2. Sectoral Analysis of SCP Patterns

Sustainable Consumption and Production patterns are analyzed throughout this study by focusing on selected consumer goods among the sectors and adapting a research approach based on an average middle-income family's annual household goods consumption in urban areas for these selected goods. Particularly for the study, the household consumption of food, paper, packaging and household e-waste is considered in terms of evaluating the environmental impacts when consumption from different electricity mixes of these products' end-of-pipe treatment equipment are applied. The current recycling applications and methods used are explained in the following sections.

SCP at household level requires awareness in successful solid waste management. There are several factors which influence the level of awareness of the public. Social and economic factors are amont those which will be explained throughout the study.

At this point, information regarding the consumer goods sectors of which the study participants in detail are presented in order to get a better understanding.

2.2.1. Organics / Food Industry

Municipal waste generation has increased significantly with the acceleration of industrialization and urbanization, especially food waste. At 1.3 billion tons per year, the food waste sector accounts for a significant proportion of total municipal waste generation, which is a major concern). Limon and Villarino (2020) state that approximately US$310 billion is lost in developing countries and US$680 billion in developed countries, which represents one-third of the United Nations Food and Agriculture Organization's food produced for human consumption. According to the World Food Program (WFP, 2016), there is enough food to feed all people, but one-third of all food is wasted

worldwide, one-seventh of the world's population goes to bed hungry, and 5.6 million children under the age of five die of starvation, or nearly 15,000 every day.

In addition, wasted foods contribute to environmental challenges, including global warming through the release of methane, a greenhouse gas. Food and Agriculture Organization (FAO) (2019a) reports that food production is the single largest cause of biodiversity loss, consuming a large proportion of the Earth's resources. According to the FAO of the United Nations (FAO, 2019b), nearly 80 percent of food waste comes from households, and about 56 percent of this waste is still consumable.

The European Union's waste management approach is based on two main pillars. The WFD (2008/98/EC Art. 4) gives priority to waste avoidance before reuse, then to recycle, recover energy an dispose of waste. On the other hand, an economic system that eliminates waste by reusing, redesigning and recovering materials and energy is advocated by the Circular Economy package adopted by the European Commission in 2015. The package introduces two main elements: a landfill ban for certain waste fractions, such as organic waste, and specific targets for the collection and recycling of different waste fractions (Irmeline et al. 2020). In this context, the organic fraction of municipal solid waste (OFMSW) has attracted significant attention due to its potential for biological treatment to recover energy in the form of biogas, while recovering nutrients through digestate utilization, stabilizing waste streams and reducing odors. Anaerobic digestion (AD) of OFMSW is a promising method for achieving these goals. (Khoshnevisan et al. 2018)

As part of a circular economy, due to the environmental and economic benefits of organic waste recovery, European authorities have been investing heavily in biogas plants, and Europe is now the global leader in AD. Previous studies have concluded that compared to incineration, composting, and landfilling, the use of AD as a waste management option provides a net environmental benefit. Biogas-based energy systems generally emit lower amounts of greenhouse gases (GHGs) than fossil-based energy systems. In 2015, SDG12.3 put global food waste reduction on its agenda, aiming at halving food waste per capita and reducing food losses along production and supply chains, including harvest losses. In Europe, the Circular Economy Package adopted in 2015 covers food waste reduction as a priority area (Irmeline et al. 2020).

Recycling food waste is one household behavior with potentially large positive impacts. Approximately the global food lost or wasted, results in 8% of global greenhouse gas emissions and

consuming 1/4 of all water used by agriculture. To create a sustainable food system, it is crucial to reduce food waste. Yet, current organic collection programs focus on structural and technological change, while neglecting the critical role that residential behavior plays in achieving this goal (Linder et al. 2018).

Stated by Sarker et al. (2022) that consumers are often unaware of waste recycling and food recovery processes in developing countries. This lack of awareness creates a major obstacle to implementing a circular economy for food waste recycling. Additionally, food industries in these countries often lag behind in recycling and valorizing food waste and are generally not concerned about it unless strong regulations are in place. Without drastically changing the product lifecycle system, behavioral insights can help bridge the gap between circular economy concepts and consumer behavior. A significant amount of food is wasted from the harvesting process to manufacturing. Evidence suggests that income levels of consumers also play a role in food waste. In developing countries, food waste is influenced by increasing economic development and a growing population. Food is highly susceptible to degradation before it is collected from fields, farms or during transportation. (Sarker et al. 2022).

Food waste streams are converted into bioenergy and used to produce valuable products through an integrated biorefinery. Food waste is becoming an important input in the circular economy, both for bioenergy and recyclables. This paper introduces the concept of circular bioeconomy and explains how to maximize the value of FW through recovery and recycling methods. A circular bioeconomy transforms renewable biological resources into high-value products, including bioactive ingredients, bioplastics and bioenergy. This approach helps to conserve future resources, reduce waste, and lower greenhouse gas emissions. When referring to bio-based products, such as food waste and biomass, the circular economy can be referred to circular bioeconomy. In such system, through various processes such as anaerobic digestion, pyrolysis, and gasification, biomass, agricultural and animal waste, and used products are reused to produce renewable energy and biofuels.

Turkey is a large country that produces a significant amount of biodegradable waste, as noted in the paper by Salihoğlu et al. (2017). Studies have shown that by using biodegradable waste as an energy source, growing energy crops on fallow land, and utilizing the biomass lost in the early stages of the food supply chain (FSC), Turkey can meet a significant portion of its energy needs. In order to make a difference in this area, efforts are needed to reduce and manage the level of Food Loss Waste (FLW).

The production of Municipal Solid Waste (MSW) in Turkey poses a significant challenge. While there are several regulations related to food loss and waste (FLW) management, the issue has not been specifically addressed. However, EU has developed a relevant strategies called EU's "Farm to Fork" and "Biodiversity" Strategies on May 20th, 2020. The EU's "Farm to Fork" and "Biodiversity" Strategies set tangible targets for transforming the EU food system while addressing key drivers of biodiversity loss. These strategies aim to reduce pesticide use and associated risks by 50%, decrease fertilizer use by at least 20%, and cut the sales of antimicrobials used in agriculture by 50%. Additionally, they tackle biodiversity loss by addressing key drivers such as overexploitation of natural resources, pollution, and invasive species (European Commission[5], 2020). In addition, regarding the subject, EU implies an Organic Action Plan that was put in force on March 25th, 2021 The Action Plan proposes the realization of organic farming in at least 25% of the European agricultural lands, and a significant increase in the production of organic aquacultural resources by 2030 (European Commission[6], 2023).

A study was conducted to determine the percentage of FLW in the food service sector in Turkey. The study used data from a variety of sources, such as FAO, Turkish Statistical Institute, national reports and responses from experienced key persons in each sector. The greatest losses were observed during the agricultural production stage of the FSC in Turkey. In middle- and high-income countries, food waste occurs primarily at the consumption stage, while in low-income countries, food waste occurs primarily at earlier stages of the food supply chain.

In the last stage of the FSC, waste management regulations in Turkey, adopted according to EU guidelines, aim to reduce the amount of biodegradable waste going to landfills by 35% by 2025 (MoEU, 2016 - Municipal Waste Management in Turkey). Thus, biodegradable waste should be sent to composting, anaerobic digestion or incineration instead of landfills. (Salihoğlu et al. 2017) Such waste handling and treatment techniques are presented in Figure 2.1. and further explained.

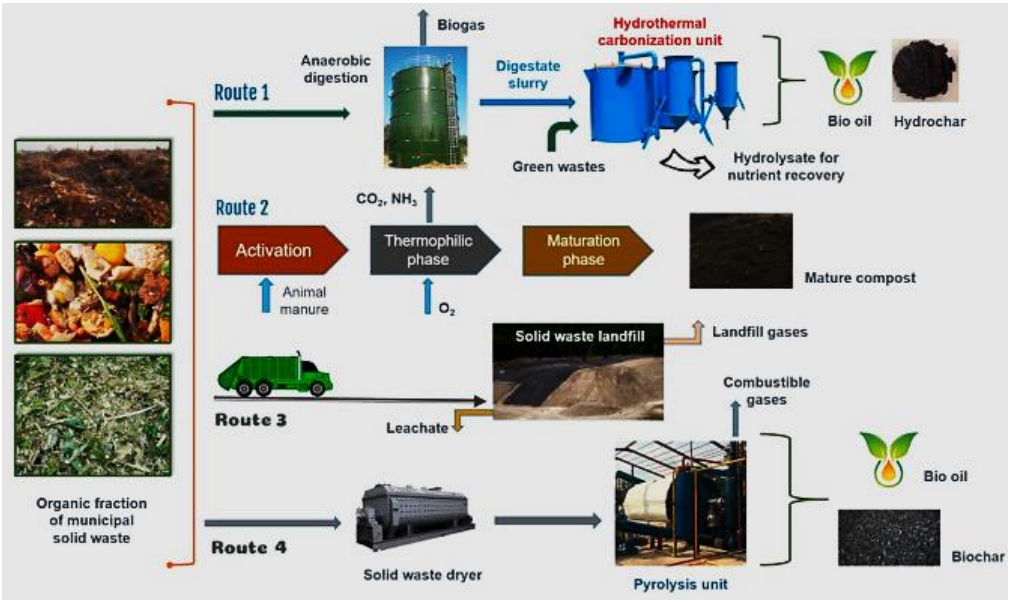


Figure 2.1. Organic waste handling and treatment techniques (Babu et al. 2021)

Incineration is a waste management technique in which waste is burned to produce heat and energy. While it is considered a safe means of disposal, it is not a feasible option due to excessive emissions and heavy metals, which cause air pollution. Landfilling is one of the most common methods of disposal for all types of waste. Landfill gas (LFG) is one of the largest anthropogenic sources of methane, accounting for 8% of global emissions. Composting (aerobic digestion) is a biochemical process in which a broad group of microorganisms are involved in the treatment. The involvement of microorganisms enhances the nutrient properties of the compost. Beyond these general properties, physical parameters like organic matter content, oxygen content, moisture content, bulk density, enzymatic activity, and the capacity of anion/cation exchange must be considered for the production of clean energy.

To address concerns such as climate change and waste management, anaerobic digestion is a promising technology. The process can be carried out at psychrophilic (10-20°C), mesophilic (30-50°C), and thermophilic (60-80°C) conditions to produce biogas or methane. Anaerobic digestion is more efficient than aerobic digestion because of higher loading rates and greater destruction of pathogens. The mechanism of digestion can be described in four stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. Hydrolysis converts proteins to soluble sugars or fatty acids; acidogenesis converts amino acids to fermentation intermediates; acetogenesis converts high-order fatty acids to acetate compounds and hydrogen; and methanogenesis converts acetates to methane.
In comparison to traditional technologies such as landfilling and incineration, AD has a smaller footprint and the potential to produce renewable energy products, thereby reducing carbon emissions

and greenhouse gases (Slorach et al. 2019). Among the alternatives mentioned, anaerobic digestion and composting are preferred over incineration and landfilling, according to Slorach et al. (2019), who discuss the principles of the circular economy and the waste management hierarchy. However, the environmental and economic sustainability of these methods will vary depending on factors such as waste composition, volume, and geographic location of generation and treatment.

In recent years, there has been an increasing demand for environmentally friendly waste treatment technologies that not only require minimal resources and are highly efficient, but also focus on the techno-economic aspects of the processes. Sridhar et al. (2021) introduce a couple of sustainable methods for converting waste to energy, in addition to the traditional methods for disposing of organic waste. Currently, 'hydrothermal carbonization' and 'supercritical water gasification' show potential for producing green energy and syngas from food waste. It is important to consider reaction parameters such as biomass-to-water ratio, feedstock composition, temperature, pressure, and catalyst dosage to achieve high gas conversion. These processes also have shorter processing times and better heat recovery, making them suitable for commercial applications.

2.2.2. Paper Industry

The paper & paper products manufacturing industry is the industry branch that includes production of cellulose and wood pulp mainly from various tree species and rarely from annual plants like jute, hemp and reed. Paper-Cardboard is classified into two main groups as cultural paper and the industrial paper in the international literature practices.

Paper is widely used as an input in the production of almost every product. The printing, publishing, and packaging industries are among the sectors that use the most paper. Paper is preferred by these sectors because it is easy to process and has a low cost. Paper, cardboard, and corrugated cardboard products have become an important sector of the packaging industry, and a large part of the packaging industry belongs to this sector.

The global paper and pulp industry is composed of small enterprises with approximately 5,000 paper and pulp mills. Global paper and cardboard production continue to grow steadily and gradually. However, different product groups in global paper and cardboard production show different development trends. The packaging and label papers, which are the most produced product group, show a development above the general growth. China, the United States, and Germany are the leading countries in global paper and paper products production. Canada, Russia, Brazil, Finland, Sweden,

and Indonesia are important producer countries in the global paper industry with their rich forest resources. Italy, France, Spain, the United Kingdom, and Austria are other important producers in Europe, while Mexico has also reached a significant production capacity and production.

According to Furszyfer Del Rio et al. (2022), the global demand for paper and paperboard products has risen steadily. The demand for paper and paperboard products is divided as follows: corrugated cardboard 38 %, printing and writing 26 %, paperboard and packaging 14 %, tissue 8 %, newsprint 6 % and other paper 8 %. The market is expected to grow by 6 Mt per year, but this growth is not evenly distributed across all sectors. For example, demand for graphic and newsprint paper is expected to continue to decline, while demand for packaging and tissue paper is expected to continue to grow. Following this dynamic, annual world paper and paperboard production could reach 550 Mt per year and 615 Mt in 2065. (Furszyfer Del Rio et al. 2022).

Suhr et al. (2015) state that historically, the pulp and paper industry has been characterized by substantial consumption of natural resources, particularly woody biomass, and various energy sources encompassing fossil fuels and a significant proportion of bioenergy and electricity. This has resulted in a considerable environmental footprint due to pollutant discharges and emissions. However, advancements in technological processes, the implementation of comprehensive environmental and energy management systems, a rise in paper recycling initiatives, and the employment of highly skilled and dedicated personnel, coupled with strategic investments in environmental mitigation measures and continuous improvement programs, have collectively facilitated a step-wise reduction in the environmental impact of the industry. Consequently, a significant decrease in emissions, ranging from 80% to 90% or more on a product-specific basis (e.g., per tonne of paper), has been achieved since approximately 1980.

Paper production consists of pulping and sheet formation. Pulping isolates cellulose fibers (lignocellulosic biomass like wood/straw) using chemicals under controlled temperature/pressure. Sheet formation converts pulp into paper with coatings/fillers. Both stages require significant resources and energy, releasing greenhouse gases and pollutants. Studies quantify these impacts. Paper production averages around 950 kg CO2-eq of greenhouse gas (GHG) emissions. However, this value exhibits significant variability across geographic regions, employed pulping methods, and the specific paper grade.

It is mentioned that paper production boasts a lengthy supply chain encompassing forestry, pulping, papermaking, energy, chemicals, and logistics. Every stage necessitates energy consumption, including process heat and power, but also upstream energy demands for raw material extraction, chemical production, and transport. While advancements within pulping and papermaking have reduced energy consumption, a life cycle assessment encompassing the entire supply chain is crucial for comprehensive evaluation. The PPI sector consumed roughly 6% of global industrial energy in 2017. Despite rising adoption of renewables, fossil fuel dependence persists, leading to substantial biogenic and fossil CO_2 emissions. Complete industry decarbonization is paramount to achieving climate stabilization and the Paris Agreement's 2°C target. The EU's 2050 climate neutrality goal necessitates a transition of the PPI towards carbon-negative operations. (Shang et al. 2022).

As stated by Suhr et al. (2015); producing one ton of paper requires on average around 11.5 GJ of primary energy. Modern pulp and paper production leads in renewable energy utilization, with biofuels accounting for nearly half of primary energy consumption. While European countries implement energy efficiency initiatives, significant process energy requirements remain.

Paper production in Turkey by modern methods began with a plant built in Izmit in 1936. Industrial and cultural paper products were only manufactured by SEKA until the 1960s, when the domestic production did not meet the demands, paper products were imported. The years between 1963 and 1979 were a breakthrough for the paper industry regarding expansion and development. During that period, SEKA was a major manufacturer; then private sectors in the paper industry as well as other industries became important figures. Turkish paper production capacity surged from 10,000 tonnes annually in 1936 to 1.63 million tonnes by 2001 (TMMOB, 2003). Recent decades have witnessed limited export attempts hampered by high costs and quality issues. However, rising industrial paper demand, particularly driven by the packaging sector, has spurred production growth. Notably, the 1984 opening of the SEKA Akdeniz plant significantly contributed to this expansion. As of 2007, paper and paperboard export were achieved to 162 countries from Turkey. The countries that making most imports from Turkey for the last three years are Iraq, Bulgaria, Romania, United Kingdom, Israel and Greece (Çabuk et al. 2014).

As mentioned in Furszyfer Del Rio’s study(2022), While global paper consumption averages 55 kg/person/year, significant disparities exist. North America leads with a quadrupled consumption (215 kg) compared to the global average. China follows at 76 kg, experiencing a notable 4.68% annual

growth. Eastern Europe mirrors China (77 kg), while Western Europe consumes nearly double (147 kg). Notably, some nations exhibit near-zero paper use.

In Turkey, there is a stable gradual increase in paper consumption, too. Paper consumption that was 5.06 million tons in 2010 reached 6.33 million tons with an increase of 25% in 2017. The product group that recorded the highest growth in production from 2010 to 2017 was the corrugated cardboard group with 921 thousand tons. Turkey's consumption which was realized as 6.33 million tons in 2017 increased its share in the world consumption to 1.54%, becoming the 16th largest market. Paper consumption per capita is both an indicator of development level of countries and an indicator of the industry's growth potential. While paper consumption per capita was 73.8 kg in Turkey in 2013, this figure became 78.1 kg in 2017, indicating a significant potential for future development (Paper and Paper Products Manufacturing Industry Report, 2018).

Due to the need for sustainability in the fight against climate change, preferences have changed in the use of many materials, and recycled paper products have become preferred in terms of energy efficiency and reduced carbon emissions. To be clearer, Eco-friendly paper is characterized by a closed-loop production cycle achieved through reverse logistics, where post-consumer waste paper is collected and reprocessed into new paper products. This process minimizes resource depletion during manufacturing. Research indicates that recycling one tonne of paper saves the equivalent of approximately 17 trees, 225 kilowatt-hours of energy, 275 kilograms of sulfur compounds, and 60,000 liters of water. The adoption of eco-friendly paper production offers a significant competitive advantage for organizations, as it demonstrably reduces their environmental footprint. Furthermore, by eliminating the reliance on virgin wood pulp, eco-friendly paper production mitigates deforestation. Additionally, eco-friendly paper manufacturing typically employs a lower volume of chemical bleaching agents compared to virgin paper production processes. Paper marketed as eco-friendly is often certified by the Forest Stewardship Council. This international non-governmental organization verifies both the sustainability of the paper product and the responsible practices of the manufacturer (Ministry of Industry and Technology, 2021). reen marketing instruments, such as eco-labels, eco-branding, and environmentally-focused advertising, demonstrably influence consumer purchasing behavior. Studies have revealed a positive correlation between consumer trust in eco-labels and eco-brands, and their propensity to purchase eco-friendly products.

To mention some of the important events that have led to the development of international standards and norms in the forestry and forest products sectors, they include international scientific

meetings on forestry, work carried out under United Nations (UN) or by other organizations, international conventions (such as the United Nations Framework Convention on Climate Change-UNFCCC, the United Nations Convention to Combat Desertification), international processes, publications and documents emerging from joint initiatives of governments and civil society organizations. The impact of economic and political developments on forestry promotes Sustainable Forest Management (SFM) and initiatives for the certification of forests, approaches on ecosystem management and participatory management understanding.

In Turkey, many studies, applications and projects are carried out to support the development of the forestry and forest products sector, both with national and international resources. In this context, international organizations cooperating with the forestry and forest products sector include the Food and Agriculture Organization of the United Nations (FAO), the United Nations Development Program (UNDP), the World Bank, the French Development Agency, the Japan International Cooperation Agency, the Global Environment Facility and the International Fund for Agricultural Development. The Food and Agriculture Organization of the United Nations (FAO) is carrying out the "Sustainable Land Management and Climate-Friendly Agriculture" and "Protection and Sustainable Management of Turkey's Steppe Ecosystems" projects in cooperation with the Ministry of Forestry and Water Affairs.

Again, in the United Nations Convention to Combat Desertification and FAO's Land Degradation Assessment in Drylands (LADA-Land Degradation Assessment in Drylands, 2013) studies, it is emphasized that more importance should be given to land degradation control, desertification, adaptation to drought and rural development studies, and country commitments are requested for these, and action plan proposals are developed. In general, the "FAO-Turkey Forestry Program", which will cover the forestry policies and institutional development, forest management and protection, forest products and services, reducing the effects of drought, is considered as an important opportunity area for the development of the sector in the coming process. The "Turkey: Forestry Policy Note" prepared by the World Bank, which provides an outside look at our country's forestry sector, is also an important document. The Global Environment Facility is a joint environmental program managed by UNDP, UNEP and the World Bank. It supports projects in the forestry sector by providing funding with its focus areas such as biodiversity and climate change (Ministry of Development, 2018).

The 1992 United Nations Conference on Environment and Development in Rio de Janeiro significantly underscored the integration of social values into Sustainable Forest Management (SFM) practices. This emphasis stemmed from the undeniable connection between forest management strategies and on-the-ground forest operations. Consequently, there has been a surge in discourse surrounding the value and implementation concepts of Sustainable Forest Operations (SFO). Three prominent approaches have emerged as key drivers in advancing the comprehension of sustainability within forest operations: (i) Environmentally Sound Forest Harvesting, (ii) Reduced-Impact Logging, and (iii) Forest Operations Ecology.

Recent research suggests that the harvesting stage is a primary contributor to greenhouse gas (GHG) emissions within the logging process. This impact is primarily attributed to the consumption of fossil fuels during mechanized operations. The release of GHGs is directly linked to the lifecycle of the fuels used – encompassing manufacture, distribution, and combustion within harvesting and extraction machinery. Notably, CO2 emissions exhibit variability based on the harvested product, local environmental conditions, the specific machinery employed, and the distance involved in extraction and hauling operations. Consequently, optimizing fuel efficiency – measured as the quantity of fossil fuel consumed per cubic meter of wood extracted – emerges as a critical strategy for mitigating the environmental impact of logging activities. From Sustainable Forest Operations (SFO) perspective, Life Cycle Analysis methodology according to the ISO standard 14040 (2006) can be used as an important tool for evaluating harvesting systems. Furthermore, the SFO concept underscores the renewed emphasis on wood as a sustainable and environmentally responsible material by promoting afforestation, reforestation, and improved forest management practices. Additionally, it encourages the utilization of wood in green building and furnishing applications. (Marchi et al. 2018).

Suhr et al. (2015) also mention that across a majority of European nations, certification programs for Sustainable Forest Management (SFM) have become a critical instrument in guaranteeing the responsible origin of wood used in manufactured products. These programs ensure a balanced consideration of economic, environmental, and social factors throughout the forestry lifecycle. The demand for certified goods is not only rising among market participants like publishers and printers, but also prompting increased government involvement in the certification landscape. This trend is exemplified by the European Union's 2004 Action Plan, titled "Forest Law Enforcement, Governance and Trade", which tackles illegal logging, and related initiatives promoting Green Public Procurement policies.

According to background study of Brack (2018), “reducing emissions from deforestation and forest degradation, plus conservation” (REDD+) is a simple concept that also proves difficulties in practice to implement. REDD+, functioning as a performance-based mechanism, seeks to incentivize nations in reducing emissions associated with deforestation and forest degradation, which contribute an estimated 10% of global greenhouse gas emissions. The program aims to establish a financial value for the carbon sequestered by forests, thereby providing incentives for forest conservation and increasing the economic penalty of deforestation. In theory, this approach mitigates drivers of deforestation such as agricultural expansion. To date, donor countries have pledged over US$10 billion, primarily directed towards ‘readiness’ activities that prepare recipient nations for REDD+ implementation. A limited number of countries are now transitioning into the investment phase, where REDD+ funds are utilized to scale up policies and measures that directly target the underlying causes of deforestation and forest degradation.

Evidently, successful implementation of these measures necessitates the allocation of resources and capacity-building initiatives for developing countries. Donor agencies and national governments, including REDD+ institutions, must play a crucial role in facilitating this assistance. The integration of these and complementary strategies into national and international climate programs, such as the Nationally Determined Contributions (NDCs) enshrined within the Paris Agreement, presents a significant opportunity to unlock additional funding streams for their execution. This convergence could significantly enhance the effectiveness of climate mitigation efforts. (Brack, 2018).

Among the waste management techniques, in the case of paper recycling, over the years these wastes have typically been sent to landfills or incineration. However, new alternatives, in particular the valorization of these materials, have been studied with growing environmental awareness. The need to maintain sustainable choices that focus on sustainable consumption and production patterns in the relevant industry has influenced and promoted this awareness (Simão, et al. 2018).

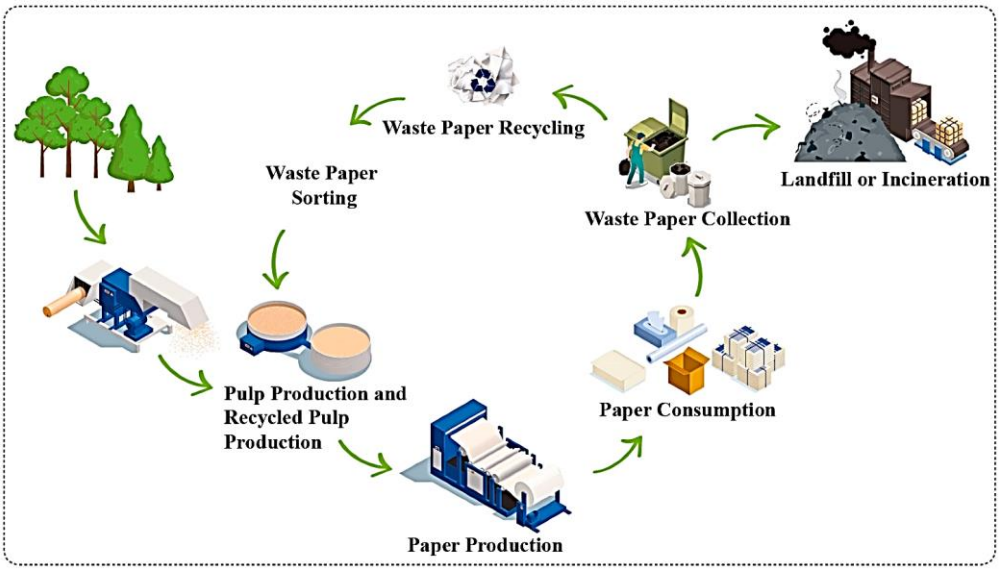


Figure 2.2. Life cycle of paper (de Oliveira et al. 2023)

2.2.3. Packaging Industry

Packaging involves the encasing or containerizing of goods to protect them from potential damage during transportation and storage. Its primary functions are to ensure the safety and marketability of a product, as well as to aid in its identification, description, and promotion (Ministry of Economy, 2020). As stated by Schaefer and Cheung (2018), product packaging functions as a powerful marketing tool for conveying messages to consumers. Available in diverse forms and dimensions, it serves as a user interface, offering consumers both user-friendly features and convenience. The essential roles of product packaging can be classified into protection, communication, convenience, and containment. The global packaging analysis focuses on assessing the demand for key material categories like plastic (both flexible and rigid), metals, glass, paper, and paperboard. Additionally, it examines associated industry sectors and the revenue generated from the sale of packaging products across diverse geographical locations (Ministry of Economy, 2020). It is mentioned by Meherishi et al. (2019) that, the packaging industry is taking a more dynamic role in the global economy, experiencing a rapid increase in market value over recent years and anticipated to reach $1 trillion in 2020 from $839 billion in 2015.

As per the data presented in the 2022 Packaging Industry Summary Report, the growth is prominently observed in the paper, cardboard, corrugated cardboard, and hard (rigid) plastic packaging industries. In 2018, the subindustries of paper and cardboard achieved a size of $301 billion, while rigid plastic packaging reached $248 billion. The report further anticipates that, within the global packaging industry in 2018, the combined share of rigid and flexible plastic packaging will

lead at 45%, followed by the paper, cardboard, and corrugated board category at 31%. The metal packaging industry and glass packaging industry are expected to account for 13% and 7%, respectively (Packaging Industrialists Association, 2022).

Covering the current situation and trends in global packaging industry, the case should be analyzed together with the Turkish perspective. The packaging industry in Turkey is a rapidly developing sector. The main factors contributing to the rapid growth of the sector include rapid urbanization, population growth, rising living standards, changes in consumption habits, the widespread establishment of shopping centers leading to an increase in retail shopping trends, growing demand for consumer products, and increase in exports. Companies operating in the sector engage in production within five main categories mainly: plastic, paper-cardboard, metal, glass, and wood packaging. Furthermore, the Turkish packaging sector has achieved world standards in terms of quality.

There is a significant increase in the number of companies that hold the ISO 9000, ISO 14001, and ISO 22000 certificates. Research and development in the sector, especially in the context of packaging design, have gained great importance to compete on a global scale (Ministry of Economy, 2020).

According to the report, as the manufacturing industry acquires new production plants, Turkish packaging industry is developing faster than that of EU countries. The United States, world's largest packaging consumer, with an industry of $140 billion was followed by China with a demand of $100 billion. With a market size of USD 28 billion, Turkey ranks 6th in Europe and ranks the 16th worldwide (Packaging Industrialists Association, 2022). Apart from the market size data, in order to better present the materials used most and analyze the packaging types consumed more, the production amounts of packaging give insights of the current practices realized in Turkey. As revealed by the examination of production data for 2021 according to material groups in the report, plastic packaging ranked the top with 37%, followed by corrugated board with 27%, glass packaging with 18%, cardboard packaging with 7%, wood packaging with 5%, metal packaging with 5% and paper packaging with 1%. The share of Turkish Packaging Material Production in 2021 is represented in Figure 2.3.

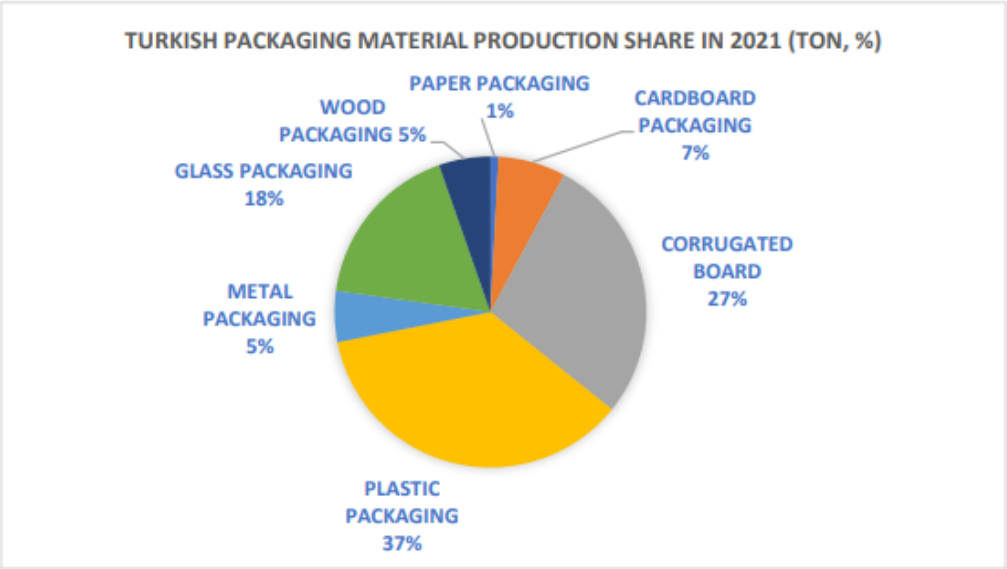


Figure 2.3. Turkish packaging material production share in 2021 (ton, %) (Packaging Industrialists Association, 2022)

In the research of Özgen & Bayazıt (2018), the concept of contemporary commercial packaging that emerged during the 1700s is mentioned. This era also saw the introduction of various machines capable of filling, weighing, labeling, and sealing products. With the commencement of transcontinental travel and shipping, the extended travel times created a demand for secure packaging to prevent spoilage during transition.

The complex connection between packaging practices worldwide and a complex network of laws reflects the ongoing efforts of countries to harmonize sustainable approaches with the essential goals of ensuring public health and protecting the environment. In this regard, there exists several packaging related regulations that countries should follow to maintain a global sustainability strategy. Of these regulations, the first one named EU's Packaging and Packaging Waste Directive (PPWD–Directive 94/62/EC) which covers a broad range of concepts including achieving circular economy. From 2009 to 2020, there was a 20% increase in the overall mass of packaging waste generated in the European Union. The PPWD establishes guidelines to prevent the generation of packaging waste and to encourage the reuse, recycling, and other methods of recovering packaging waste. It outlines the requirements that all packaging introduced to the EU market must adhere to, with the goal of reducing the disposal of packaging waste and fostering a more circular economy. As a component of the new CE Action Plan and of the EU Green Deal, the European Commission proposed a revised version of the PPWD in November 2022. The primary goal of this initiative is to guarantee that every form of packaging becomes reusable or recyclable in a financially viable manner by 2030. The

objective is to strengthen the fundamental criteria for packaging to facilitate its reuse and recycling, increase the incorporation of recycled materials, and enhance the enforceability of the requirements. Additionally, measures are anticipated to address excessive packaging and minimize overall packaging waste (Ragonnaud, 2023). The regulation aims to set forth criteria on the entire packaging process, encompassing aspects from raw material acquisition to ultimate disposal, with a focus on environmental sustainability and labeling. It covers the approval for market placement, incorporating the concept of Extended Producer Responsibility (EPR) for the collection, treatment, and recycling of packaging waste. It applies to all types of packaging materials, and adherence to the regulation is mandatory for packaging to be authorized for market entry. Member States are prohibited from restricting or hindering the market placement of compliant packaging (Ragonnaud, 2023.) PPWD also highlights the concern about Plastic carrier bags. It aims to achieve a sustained reduction in consumption; just as it is proposed in the EU Directive of Reducing the Consumption of Lightweight Plastic Carrier Bags – published in April 2015. The Directive similarly aims to decrease the use of thin plastic bags to mitigate environmental impacts but in a more detailed way. It typically includes measures such as charging for bags, promoting reusable alternatives, and implementing strategies to minimize plastic bag usage, all contributing to the reduction of plastic pollution and fostering environmental sustainability (EU, 2015).

As it's been discussed for several years, the adoption of SDGs is crucial to limit the global warming and achieve a sustainable future for all, including better management in global resources and relevant environmental, social and governance related global challenges. The term Zero Waste introduced in the light of SDGs highlights the need for reducing the amount of waste in the first hand by keeping the products in use as long as its life cycle allows. Considering such, the packaging industry holds great opportunities which enable consumers and manufacturers to practice sustainable choices that mostly rely on the idea of closing the loop. Concepts related to relevant subjects are discussed in "Towards a circular economy: A zero waste program for Europe" which was published in 2014.

The main methodologies and rules are addressed by Turkish Ministry in the document named Regulation on Control of Packaging Waste (Ambalaj Atıklarının Kontrolü Yönetmeliği) that was published in December 2017; revised in June 2021. The regulation aims to sustainably protect and enhance the environment by determining the strategies and policies, as well as the administrative, financial, and technical procedures and principles on sustainable packaging activities (Regulation on Control of Packaging Waste, 2023).

Different but not apart from Regulation on Control of Packaging Waste, Turkey has started to imply “Procedures and Principles Regarding Mandatory Deposit Management System Applications" which was published in April 2022 on the official website of Turkish Environment Agency (Turkish Environment Agency, 2023). The system, constituted by the Ministry of Environment, Urbanization, and Climate Change, is based on the return and refund of a specified deposit amount after the consumption/use of products released into the market, for which a specific deposit fee is collected (Turkish Environment Agency, 2021). The Deposit Management System is an effective tool used to create a successful collection system and to increase collection quantities, especially for materials that pose challenges in collection and have adverse effects on the environment and human health when they become waste. The primary focus is on including single-use sales packaging made of materials such as glass, polyethylene terephthalate (PET) plastic, and aluminum, which are used for the commercial release of beverages for human consumption. There also exist many standards implemented by Turkish Standards Institution (TSE) including the Standards of “General Principles of Packaging – Marking and Labelling of Packaging Products.”

Schaefer and Cheung, (2018) conclude that there is a need for innovative packaging with enhanced functionality to address various consumer requirements. This includes providing food with fewer preservatives, meeting heightened regulatory standards, and enabling cradle-to-grave tracking in packaging to serve as a safeguard against legal issues. Furthermore, smart packaging plays a role in expanding markets globally, aiding in compliance with stringent national and international food safety regulations, and acting as a defense against potential threats such as food bioterrorism.

Considering the impact of packaging on various ecosystems; there is an opportunity to examine its role within the circular economy (CE), which is fundamentally designed to be restorative and regenerative. Departing from the linear take-make-use-dispose model of packaging, more sustainable approaches are emerging, focusing on reducing packaging usage and effectively managing packaging waste through processes such as separation, collection, recovery, and recycling of used packaging. The “New Plastics Economy Global Commitment” movement, initiated by UN and the Ellen MacArthur Foundation, has garnered the support of 250 organizations, including major food and beverage companies, governments, and packaging manufacturers. Its objective is to eliminate plastic waste and pollution at the source. Additionally, over 60 countries have implemented bans and levies to address the issue of single-use plastic packaging waste (Meherishi et al. 2019).

Sustainable Packaging Coalition defined the case. To call it sustainable packaging, sustainable energy and recycled materials should be utilized in all steps of production, distribution, and material sources, the maximum feasible amount of recycled materials should be incorporated, a product life-cycle analysis, ensuring that the materials used contribute to overall health solutions throughout the entire process should be conducted. It should be designed with a physical emphasis on balancing material and energy usage and integrated qualities that promote reuse and renewability, adhering to an industrial cradle-to-cradle cycle (Schaefer & Cheung, 2018).

Life cycle assessment (LCA) tools, used to gauge the relative sustainability of packaging, should be employed efficiently, encompassing a broad spectrum of environmental impacts while focusing on specific packaging elements. Many LCA studies on materials often lack a comprehensive consideration of all environmental impacts, leading to frequent interpretations based on limited elements. LCAs are commonly integrated into the ecodesign process during the initial development of packaging. Some commercially available tools include Comparative Packaging Assessment by the Sustainable Packaging Coalition, PackageSmart, the Guide from the Australian Packaging Covenant, and the Packaging Impact Quick Evaluation Tool. Furthermore, many tools used by packaging professionals to estimate package sustainability lack complete inputs. Additionally, previous sustainability assessments were either qualitative or not applicable to specific packaging types, such as intelligent packaging (Boz et al. 2020). In the last twenty years, terms like active packaging, intelligent packaging, and smart packaging have been brought in literature and are frequently employed interchangeably. These terms collectively denote packaging systems utilized for perishable goods such as foods, beverages, pharmaceuticals, cosmetics, and more (Schaefer & Cheung, 2018).

Efforts have begun in the EU authorities to ensure that all packaging in the EU market is economically reusable or recyclable by 2030. In this regard, numerous companies, such as Nestlé, McDonald’s, PepsiCo, Unilever, Kraft-Heinz, and Coca-Cola, have established targets in their action plans to enhance the sustainability of their packaging by 2025 and beyond. These objectives encompass improved recycling efforts, increased use of recycled materials, diminished reliance on virgin materials, sustainable sourcing, weight reduction, and the design of packaging for improved recovery. The commitments made, involving the design and selection of packaging elements, material choices, and modifications to the value chain, necessitate significant resource and all with the anticipation of achieving greater market appeal and consumer satisfaction (Boz et al. 2020).

Du Rietz and Kreme (2023) mention that Deposit-Refund Systems (DRS) for beverage packaging boast a lengthy history, with their initial conception revolving around product reuse. The advent of metal beverage cans spurred the incorporation of recycling into these systems, and many became mandatory through legislative measures known as "bottle bills." Extensive research has established a robust understanding of the post-consumption phase within DRS. These studies consistently demonstrate the efficacy of DRS in facilitating the return of both reusable and recyclable beverage containers due to the high retrieval rates achieved.

In Pellengahr et al. (2023), End-of-life (EoL) management is gaining attention as a means to integrate plastic packaging into circular economy models. Integrating plastic products into a circular economy holds promise for mitigating the environmental and climate impacts of certain disposal options, such as emissions from incineration or leakage from landfills, which can lead to fragmentation into microplastics. Life Cycle Assessments (LCAs) are frequently used to determine the environmental sustainability of EoL options as well as recycling options for plastic products. An overview of potential waste treatment routes is shown in Figure 2.4.



Figure 2.4. Life Cycle of plastic packaging and overview of potential waste treatment routes (Pellengahr et al. 2023)

2.2.4. Household E-waste (Electronic waste (e-waste)) Industry

Technological products have always played an important role in human life. In particular, the widespread adoption of technology in the last quarter century has led to increased production, and the level of technology consumption has also increased every day for this reason. Technology manufacturers have given a lifespan to the devices they produce in order to increase the consumption of technology, and devices that have reached the end of their lifespan have also become waste. This is a global threat for all developed and developing countries. According to the data of the Global E-waste Statistics Partnership (GESP) for 2019, the volume of e-waste has grown by 21% in the last 5 years. E-waste has become the world's fastest growing waste stream. According to this growth rate, it is expected that the volume of e-waste, which was 53.6 million metric tons in 2019, will reach 74 million metric tons by 2030 globally (Yıldırım, 2023).

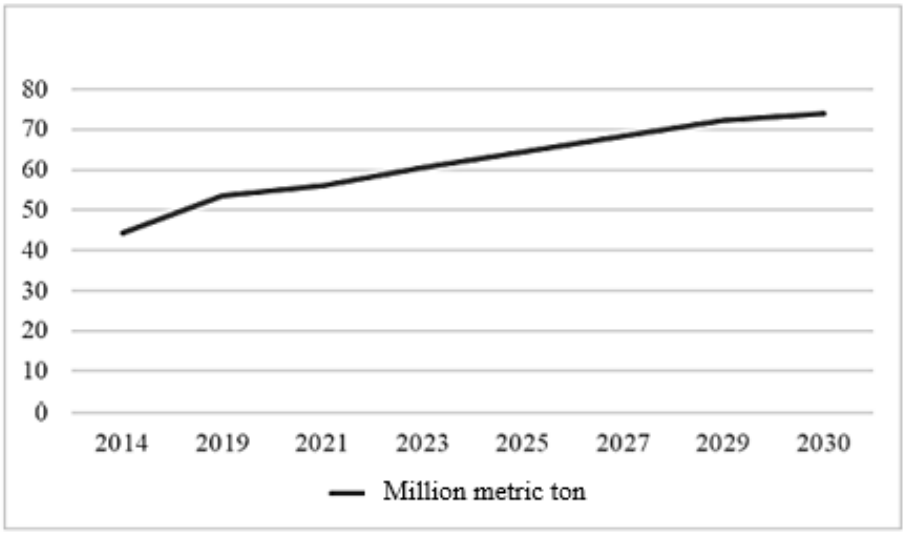


Figure 2.5. The volume of e-waste growth (Yıldırım, 2023)

According to Liu et al. (2023) currently, there is no universal definition of e-waste, as it is defined differently in each country or region. The Organization for Economic Cooperation and Development defines e-waste as all electronic equipment that is at the end of its life cycle. According to the EPA, electronic waste includes large electronic equipment, small electronic equipment and consumer electronics. The definition most widely accepted of e-waste is stated in the EU Directive on Waste Electrical and Electronic Equipment (WEEE), which will be discussed in detail later. This directive defines e-waste as waste electrical and electronic equipment, including all parts, components and consumables that are used as products at the time of discarding (Yıldırım, 2023).

In the report published by The International Telecommunication Union (ITU, 2022) in addition to their well-known domestic and institutional uses, EEE is experiencing exponential growth across various sectors, including transportation, healthcare, security systems, and renewable energy generation through photovoltaics. This trend extends beyond traditional domains, as everyday products like furniture are increasingly incorporating electrical components, consequently contributing to the burgeoning global burden of electronic waste (e-waste). Furthermore, the burgeoning Internet of Things (IoT) sector heavily relies on EEE integration, encompassing sensors and devices that underpin the concepts of "smart homes" and "smart cities."

The composition of e-waste is highly complex. Specifically, e-waste typically contains steel, iron, polymer plastics, non-ferrous metals, glass, wood, plywood, printed circuit boards, concrete, ceramics, and rubber. Iron and steel make up approximately 47% of the waste by weight, plastics account for around 21%, copper for about 7%, glass for approximately 5%, and the remaining weight is comprised of other materials.

The E-waste Statistics Guidelines on Classification Reporting and Indicators – Second Edition (Forti, Balde, and Kuehr 2018) divides EEE into six general categories as

1. Temperature exchange equipment (includes refrigerators, freezers, air conditioners, and heat pumps)
2. Screens and monitors (televisions, monitors, laptops, notebooks, and tablets)
3. Lamps (fluorescent lamps, high intensity discharge lamps, and LED lamps)
4. Large equipment (washing machines, clothes dryers, dishwashing machines, electric stoves, large printing machines, etc.)
5. Small equipment (vacuum cleaners, microwaves, ventilation equipment, toasters, electric kettles, electric shavers, scales, etc.)
6. Small IT and Telecommunication equipment (mobile phones, Global Positioning System (GPS) devices, pocket calculators, routers, personal computers, etc.)

This categorization currently complies with the WEEE directive adopted by the member states of the European Union (European Parliament 2003).

Islam et al. (2020) state that considering that e-waste contains valuable metals as well as numerous dangerous materials, it is possible that a large amount of hazardous metals (such as Cd, Hg, Pb, and Cr) from e-waste could increase the toxicity levels of ecosystems. The long-term persistence of e-waste in the environment may also increase the risk of exposure to hazardous materials, which could lead to serious pollution of groundwater and harm to human health. The long-

term persistence of e-waste in the environment may also increase the risk of exposure to hazardous materials, which could lead to serious pollution of groundwater and harm to human health. In recent years, it has been reported that the production of electronic waste has reached 50 million units per year. However, only 20% of the total production is recovered.
It is worth noting that e-waste materials contribute 70% of the total toxic materials to the environment. Therefore, recycling e-waste is crucial in protecting our environment.

As stated in Yıldırım (2023), when the consumption of global electrical and electronic products is examined, China and the United States, due to their large populations, are among the countries with the highest consumption. The two countries mentioned are also among the countries with high technological production and consumption capacity. According to the report prepared by GESP in 2019, China ranks first in the world by producing more than 10 million metric tons of e-waste. China. is followed by the United States with an average of 7 million metric tons (Yıldırım, 2023)

According to Compagnoni (2022), the global production of WEEE increased by 21% from 2014-2019 and is expected to almost double by 2030. The ITU report (2022) reveals that in 2019, approximately 53.6 million metric tons (Mt) of e-waste (excluding PV panels) were generated, which is equivalent to 7.3 kg per capita. In 2019, Asia produced the highest quantity of WEEE with 24.9 million metric tons, equivalent to 5.6 kilograms per capita, followed by the Americas (13.1 million metric tons, 13.3 kilograms per capita), Europe with 12 million metric tons (16.2 kilograms per capita), and Africa (2.9 million metric tons, 2.5 kilograms per capita). In Europe, only 42.5% of all waste electrical and electronic equipment has been officially collected and recovered, compared to 17.4% globally. Compagnoni also reported that in 2019, the majority of global e-waste was comprised of small equipment (17.4 Mt), large equipment (13.1 Mt), and temperature exchange equipment (10.8 Mt). At 6.7 Mt, 4.7 Mt, and 0.9 Mt, respectively, screens and monitors, small IT and telecommunications equipment, and lamps accounted for a smaller portion of e-waste generated in 2019. The e-waste category with the highest increase in total weight generated since 2014, averaging 7% per year, is temperature exchange equipment. According to the 2019 data of GESP, Turkey's e-waste collection rate is 18% with a population of 83,023,000. While the annual e-waste production is 847 kt, 125 kt is collected, and the per capita e-waste production is 10.2 kg (Forti et al. 2020).

In order to effectively manage the e-waste problem, countries apply different methodologies in terms of waste handling in general. In Turkey, e-waste management is carried out by organizations that have been authorized by the Ministry of Environment and Urbanization and General Directorate

of Environmental Management. There are 3 organizations that have obtained this authorization for e-waste; AGİD (Aydınlatma Gereçleri İmalatçıları Derneği), TÜBİSAD (Turkiye Bilişim Sanayicileri Derneği), and ELDAY (Elektrikli ve Elektronik Geri Dönüşüm ve Atık Yönetimi Derneği İktisadi İşletmesi) (Yıldırım, 2023). At this point, it is important to mention the policies, regulations, legislations, and initiatives followed worldwide, including a detailed analysis of EU and Turkish applications. Although 71% of the world's population is covered by some form of e-waste policy as of October 2019, more efforts need to be made to implement and enforce these policies to promote efficient collection and recycling infrastructure (ITU, 2023).

The European Union (EU) has two directives, the Waste Electrical and Electronic Equipment (WEEE) Directive 2002/96/EC and the Restriction of Hazardous Substances in Electrical and Electronic Equipment (RoHS) Directive 2002/95/EC. These directives were implemented on February 13, 2003, to regulate the collection, recycling, and usage of hazardous substances in e-waste(European Commission[4], 2021). Liu et al. (2023) define e-waste as the waste electrical and electronic equipment (WEEE) covered by the WEEE Directive. WEEE is mainly produced by Organization for Economic Cooperation and Development (OECD) countries but developing countries have shown a significant increase in WEEE generation. In response to public objections to the importation of toxic wastes into Africa and other developing countries, the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal was adopted. Its objective is to protect human health and the environment from the adverse impacts of hazardous waste. To address these challenges, the RoHS Directive restricts the use of certain hazardous substances in electrical and electronic equipment, while the WEEE Directive promotes their collection and recycling. These EU laws aim to ensure the safe and sustainable disposal of such equipment (European Commission[7], 2021).

Cardamone et al. (2021) notes that there are already global policies for the recycling of electronic waste, and that this depends largely on consumer behavior and local markets. In Europe, all countries have their own WEEE regulations that promote recycling. Although China has formal commandments for WEEE management, it is still working on expanding its recycling capacity.
The United States is the world's largest producer and consumer of electronics, in addition to being the primary destination for e-waste dumping. Many other countries are still in the developing stage of e-waste management protocols.

There are a number of EU initiatives that shed light on practices of different countries. StEP brings together industrial, scientific, governmental and non-governmental stakeholders. The initiative has established guiding principles for developing e-waste management systems and legislation. Additionally, it is worth noting the establishment of the E-waste Coalition on March 21, 2018. The International Telecommunication Union (ITU) and six other entities of the UN have signed a memorandum of understanding to work together on the management of e-waste in the development of an E-waste Coalition. The signatories are committed to increasing collaboration, building partnerships, and supporting Member States in addressing the global WEEE challenge (ITU, 2022).

Having covered the situation globally, it is crucial to consider by which policies and regulations e-waste is managed and controlled in Turkey. The Ministry of Environment and Forestry published the Regulation on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment in the Official Gazette No. 26891 on May 30, 2008, in Turkey. Its purpose is to establish procedures and principles for environment-friendly recovery and disposal of WEEE through restriction of use of certain hazardous substances in WEEE, to determine which uses are excluded from such restrictions, and to establish administrative, legal and technical principles for import control of WEEE. The main regulation governing this subject is the Regulation on the Control of Waste Electrical and Electronic Equipment. It also lays down principles for the reuse, recycling and recovery of electrical and electronic equipment and sets targets for reducing the generation and disposal of WEEE (Islam et al. 2020).

Globally, e-waste handling practices are being improved with the help of internationally and nationally applied policies and regulations. However, there is still a significant need to move away from the linear approach of the economy and to adopt instead a closed loop system in industry. Several initiatives promoting less resource depletion and greener technologies and behaviors worldwide are based on the application of the Circular Economy approach in the e-waste sector. It is crucial to mention how CE can be integrated into the Extended Producer Responsibility approach.

Barapatre and Rastogi, (2022) conclude that China and India, despite lacking a national registry, have successfully implemented the EPR legislation system to monitor the production of EEE and establish a subsequent manufacturer take-back system. A thought paper on the issue clearly states that existing EPR policies for electronics only serve as a limited means of effective e-waste management. Therefore, additional pathways must be explored. This includes advocating for initiatives such as DRS, public-private partnerships, and an all-actors engagement model. One

effective way for producers to achieve this is through the adoption of green product design. Liu et al. (2023) provide detailed information on green design in their paper, highlighting its effectiveness in reducing e-waste at the source. The focus is on greening the entire product life cycle. Design principles should consider the environmental attributes of the device, including its ability to be disassembled, recycled, serviced, and reused, thereby simplifying the recycling process for end-of-life electronic devices.

2.3. Life Cycle Assessment (LCA) Methodology

To perform sustainable development methods in decision-making processes like production, design and politics, a widely used quantitative environmental assessment tool Life Cycle Assessment (LCA) is introduced. European Commission, states that LCA is equipped to deliver comprehensive, integrated environmental analyses that enhance the establishment of national and international policies, according to the Better Regulation Toolbox from the European Commission. The life cycle assessment (LCA) approach is a way to evaluate and quantify the environmental effects of anthropogenic systems, such as products, businesses, and countries, from "cradle to grave" approach (Suski,et al. 2021). The individual use, adaptation and practice of LCA for all potential applications are based on ISO 14040 and ISO 14044. LCA technique with proper justification could be applied in studies, which cover specific parts of the life cycle (e.g. waste management, components of a product) (ISO 14040, 2006).

3. MATERIALS AND METHODS

The environmental impact assessment through LCA methodology based on ISO 14040-44 (ISO 14040, 2006; ISO 14044, 2006) standards is applied to identify the end of pipe treatment environmental impacts of waste when different recycling rates and shares of renewable energy applied in overall electricity consumption during treatment. The study is conducted in four main steps as (1) goal and scope definition, (2) inventory analysis, (3) life cycle impact assessment, and (4) interpretation.

A detailed Literature Review on SCP is expressed and recycling inventory data on selected sectors are consolidated which are accessed (i) through up-to-date literature search / findings, (ii) through scientific datasets obtained from GaBi 8.0 software and Ecoinvent database, and (iii) from an integrated waste management company (Company A) located in Tuzla, Istanbul, Turkey. Consumer goods subjected to this study include food (organics), paper, packaging and household e-waste. National consumption amounts are analyzed and next, the study focuses on the amounts of food waste (FW), paper waste, packaging waste (plastics only) and e-waste of an average Four-People Middle-Income Family's (will be referred to as "FPMIF") production. By conducting the study with using national recycling rates & energy shares and EU's targeted recycling rates and Turkey's 2030, 2035 and 2050 targeted renewable shares; the environmental impacts of the recycling processes are examined. After gathering the inventory data, life cycle impact assessment is performed through running the GaBi 8.0 software for the recycling treatment phase with LCA, CML 2001 methodology. Interpretation of the results takes place at the end. Outputs of the characterization are discussed in the following parts. After characterization, normalization and weighting take place which give better understanding about the study.

Among many waste management techniques, different recycling alternatives are selected for different types of consumers' goods, which require different amounts of electricity consumption. The choices are done wisely by focusing on commonly preferred waste management methods in Turkey. In this manner, anerobic digestion for food waste/organics and mechanical recycling for paper, packaging and household e-waste have been selected.

3.1. Goal and Scope of Definition

The purpose of this study is to compare the environmental impacts of annual household waste production from daily short-term consumables and long-term industrial products, which are determined through focusing on the recycling phase of a product's life cycle, by comparing different efficiencies in the recycling process and different shares in the renewable energy consumed by recycling equipment. The study also considers the status of changing public awareness and consumer behaviour in solid waste management throughout the years. The comparison is done by inserting national energy source shares targeted for the years 2030, 2035 and 2050 with connecting output data that consider relevant recycling rates targeted to be reached in that year. The aim is to determine the environmental impacts arising from treatment of FPMIF waste in 2020, 2030, 2035 and 2050 with relevant waste production projections. By increasing the share of renewable electricity and recovery rate of materials through integrating policies, improving consumer behaviour on sustainable selections and developing legal frameworks that focus on more efficient waste management techniques and alignment with EU Targets and strategies; SCP practices and transition to greener and circular economy pathways are examined. The study first examines the environmental impacts of current situation (baseline - 2020), 2030, 2035 and 2050 target recycling rates stated in the EU Waste Framework Directive (Scenarios – Set 1) with the given electricity shares for 2020 - stated in Turkey's National Energy Plan - assumed to be consumed by the recycling equipment.

Table 3.1. Definition of the applied scenarios – Set 1

Scenarios	**Recycling Rate – EU WFD, Target Shares**	**Electricity Generation Profile**
Scenario I	- 2020 MSW Recycling Ratio - Combined Fossil Fuel and Renewable Energy fired recycling equipment	Baseline – 2020 Scenario Turkey's National Energy Plan Target Share in Electricity Generation (Fossil Fuel Dominant and Renewable Energy Share)
Scenario II	- 2030 MSW Target Recycling Ratio - Combined Fossil Fuel and Renewable Energy fired recycling equipment	
Scenario III	- 2035 MSW Target Recycling Ratio - Combined Fossil Fuel and Renewable Energy fired recycling equipment	
Scenario IV	- 2050 MSW Target Recycling Ratio - Combined Fossil Fuel and Renewable Energy fired recycling equipment	

Following up the results examined in the first set, the study then considers the environmental impacts by integrating the current situation (baseline - 2020), 2030, 2035 and 2050 target recycling rates with the target electricity shares according to source consumed by the recycling equipment that rely on Turkey's National Energy Plan and Decarbonization Roadmap (Net Zero in 2050) for these years. The methodology of such integration, which creates the core of this study, is explained in the table below in a detailed way.

Table 3.2. Definition of the applied scenarios – Set 2

Scenarios	**Recycling Rate –** EU Waste Framework Directive, Target Shares	**Electricity Generation Profile** - Turkey's National Energy Plan and Turkey's Decarbonization Roadmap (Net Zero in 2050)
Scenario V	- **2020** MSW Recycling Ratio - Combined Fossil Fuel and Renewable Energy fired recycling equipment	Fossil Fuel Dominant and Renewable Energy Share in Turkey's Electricity Generation Baseline – 2020 Scenario Turkey's National Energy Plan Target Share in Electricity Generation
Scenario VI	- **2030** MSW Target Recycling Ratio - Combined Fossil Fuel and Renewable Energy fired recycling equipment	Fossil Fuel and Renewable Energy Share in Turkey's Electricity Generation 2030 Scenario - Renewable Energy Shares according to Turkey's Decarbonization Roadmap (Net Zero in 2050)
Scenario VII	- **2035** MSW Target Recycling Ratio - Combined Fossil Fuel and Renewable Energy fired recycling equipment	Fossil Fuel and Renewable Energy Share in Turkey's Electricity Generation 2035 Scenario - Renewable Energy Shares according to Turkey's National Energy Plan Target Share in Electricity Generation
Scenario VIII	- **2050** MSW Target Recycling Ratio (Assumed) - Combined Fossil Fuel and Renewable Energy fired recycling equipment	Fossil Fuel and Renewable Energy Dominant Share in Turkey's Electricity Generation 2050 Scenario - Renewable Energy Shares according to Turkey's Decarbonization Roadmap (Net Zero in 2050)

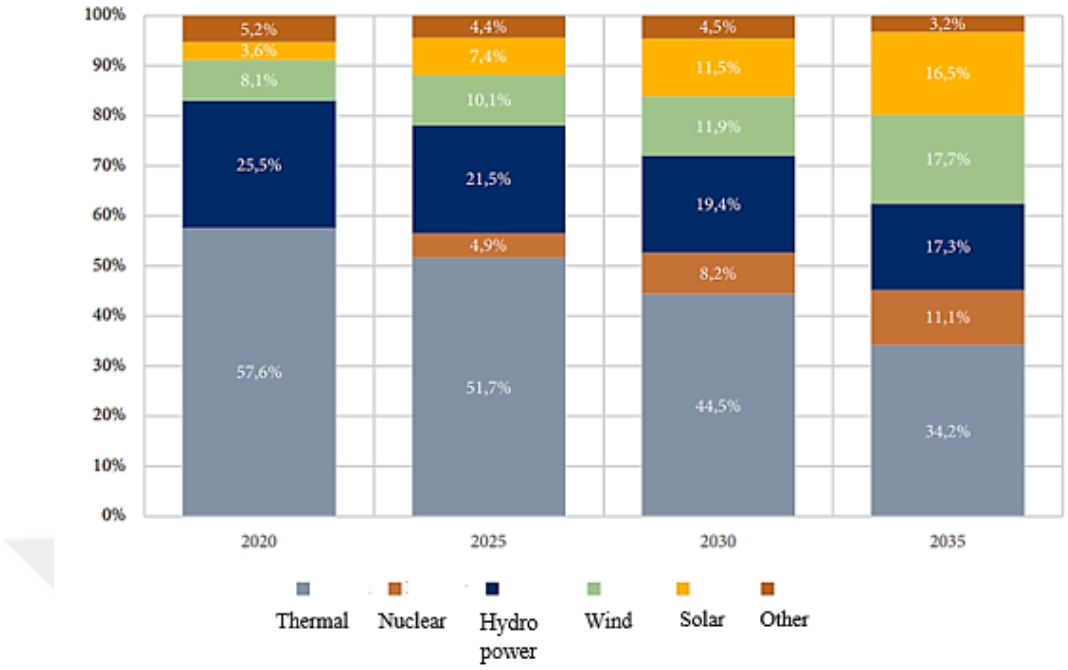


Figure 3.1. Share of electricity generation based on source (National Energy Plan, 2022)

3.2. Functional Unit

The functional units throughout the study in selected sectors are determined wisely which aim to reflect reasonable results when the GaBi 8.0 software is run. According to literature search on sectoral inventory data, it is observed that majority of studies mainly focus on considering a functional unit of 1 kg of each item in general. The input and output inventories of recycling treatment in LCA are adjusted to larger units to obtain reasonable findings. The study focuses on the recycling part of the entire life cycle of the product; therefore, the relevant functional units are related with data on waste production. Such data is mostly collected and represented in larger amounts since the country-level consumption is taken into consideration mainly. Data on FPMIF's waste production are presented in the table below, which explains why the functional units are chosen as follows. Within the study the household goods consumption in 2030 and 2050 are considered with the relevant population projections. future waste production amounts are reached through multiplying the unit production value with 2030 and 2050 projected populations. The amount of waste production highly depends on public awareness and public training on sustainable solid waste management. Therefore, the society's behavioral development throughout the years which are impressed through internal (demographic characteristics and psychological aspects) and external factors (waste treatment facility infrastructure and service provision on recycling behavior) plays a key role.

The population to be reached in 2030 and 2050 are assumed to be around 93 million and 105 million respectively. (TURKSTAT, 2021) Results made clear that the functional unit should be represented in unit tons.

Table 3.3. Waste Production according to years

Consumer goods	Year data was available	Waste Production (million ton/year)	Waste production per capita (ton/cap.year)	Waste production 4-people (ton/year)	2030 waste production 4-people (million ton/year)	2050 waste production 4-people (million ton/year)
Organics	2022	17.40	0.20	0.82	76.15	85.98
Paper	2022	5.24	0.06	0.24	23.19	26.18
Packaging	2020	3.70	0.04	0.18	16.19	18.28
E-waste	2020	0.85	0.01	0.04	3.72	4.2

1 ton of waste production has been implemented for three of the four consumer goods sectors included in the study. The remaining sector is categorized under long-term consumer goods, which holds relatively longer lifespans in terms of and FPMIF's consumption; "100 items of e-waste" has been selected in that manner.

Table 3.4. Summary of the methodology implied

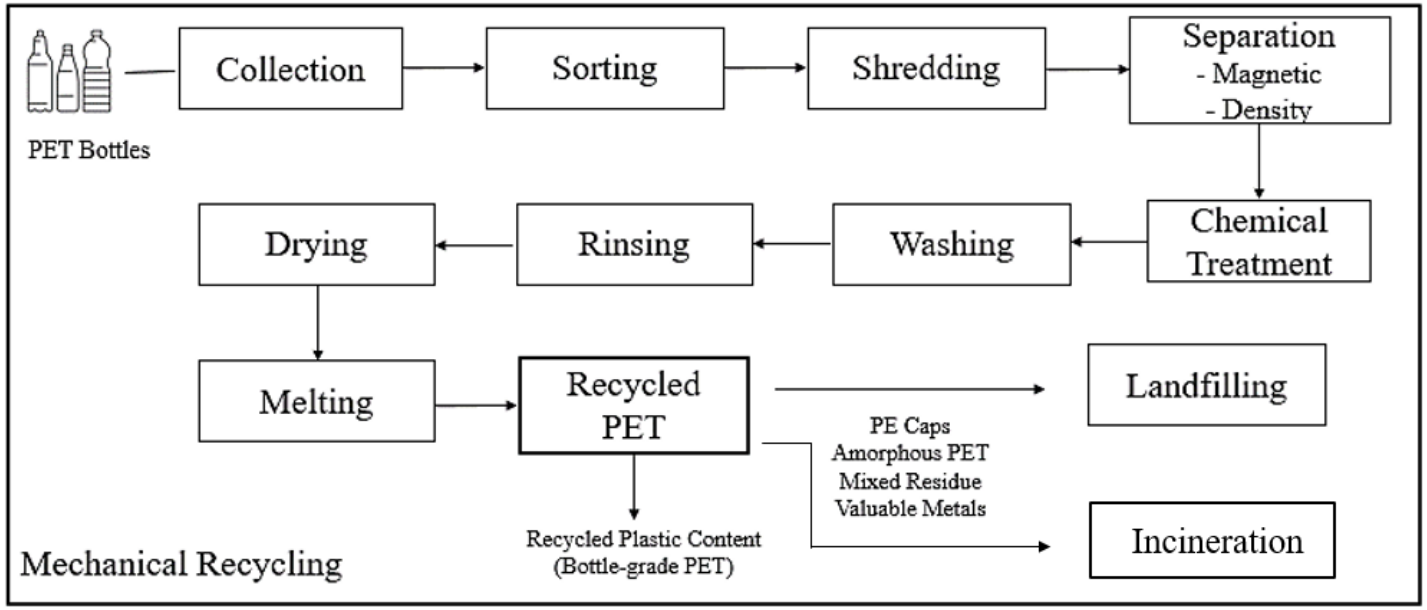
Name of the Sector	Impact Assessment Methodology	Functional Unit	Data from
Organics / Food	CML2001 Aug, 2016	1 ton of organic waste	Haupt et al. 2018
Paper		1 ton of paper waste	Haupt et al. 2018
Packaging		1 ton of packaging waste	Haupt et al. 2018
Household e-waste (including individual equipment)		100 items of e-waste	Company A, Tuzla, Istanbul, Turkey, 2018

3.3. System Boundaries

The system boundary and flow chart followed in this study are presented below. While deciding on recycling/recovery alternatives, it is aimed to emphasize more on energy consuming processes which basically include recycling via mechanical and thermal treatment. Also, the example flowchart is given from mechanical recycling of waste plastic packaging (PET Bottles) with presented inputs and outputs.

INPUT

- Plastic Waste
- Energy
- Water
- Chemicals



OUTPUT

- Emissions

Figure 3.2. Flowchart of PET bottle mechanical recycling

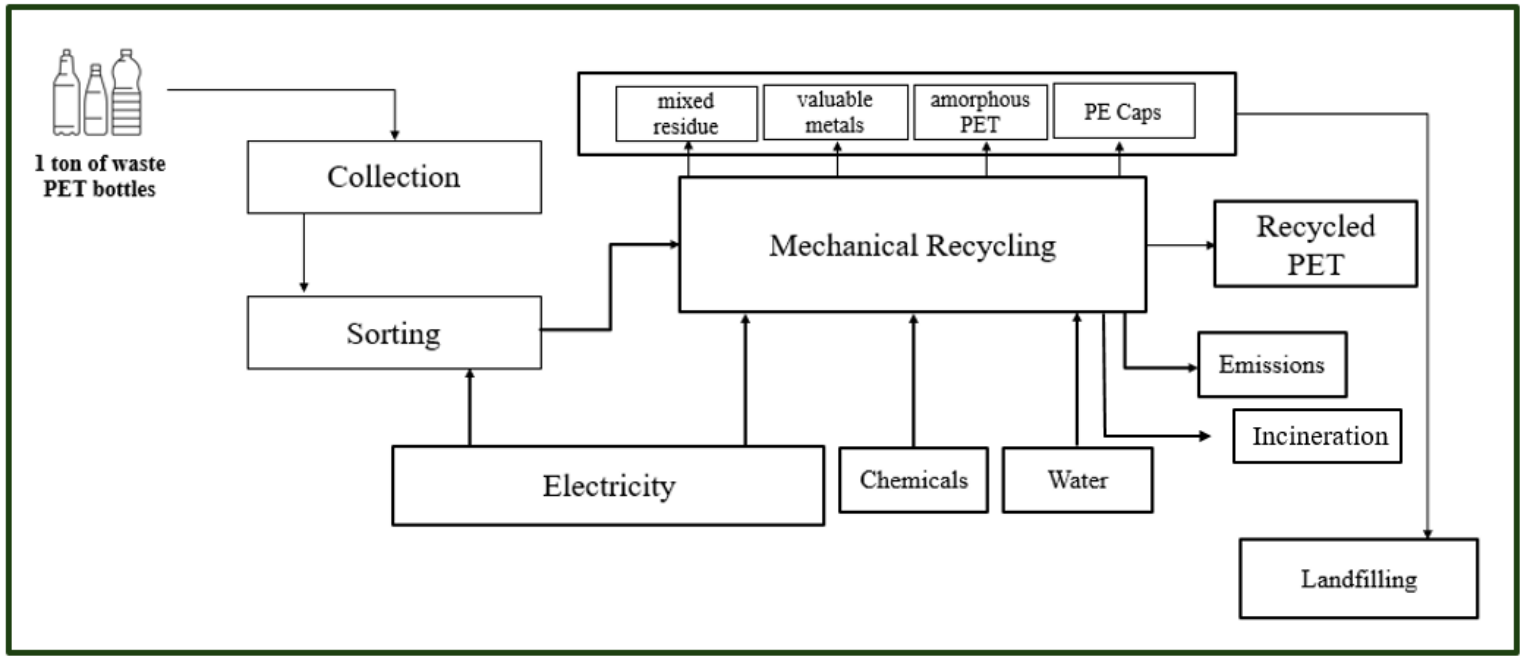


Figure 3.3. Flowchart of PET bottle recycling followed in the study

Inventory included in the study (only for plastic packaging)

Inputs
- Plastic Waste
- Energy (including natural gas)
- Water
- Chemicals

Outputs
- Emissions to
  air
  soil
  water

3.4. Life Cycle Inventory Analysis and Key Assumptions

A life cycle inventory analysis is conducted through gathering relevant data from different sources such as literature findings, Ecoinvent database, GaBi database and real company reports. By doing so, the required input and output data are determined and integrated in the assessment, relying on several parameters with several assumptions. In the study, the recycling input and output data for food, paper and packaging sector are obtained through an article, which presents a comprehensive work by consolidating, and adjusting the results gathered from dozens of articles and sectoral reports that at the end gives applicable and up to date data on relevant sectors.

This study considers recycling as a whole unit process of waste treatment by excluding the intermediate steps such as sorting, shredding, cleaning, pressing etc. The recycling methods differ in between the types of consumer goods but mainly gather around mechanical recycling in general. While the intermediate steps of mechanical recycling, that generally include collecting, cleaning and sorting the waste are not covered in detail, the unrecycled portion of the waste is assumed to be sent to incineration and landfilling. The flow of waste collection – therefore transport of waste from the source to waste treatment facility – is not included in the system boundaries and flow charts. Similarly, impacts of processes like dismantling and sorting of waste are not considered in the flow charts due to inconsistencies and inadequacy in the data. However, the amount of electricity consumed during the sorting process is included in the total electricity consumption of relevant recycling equipment. In addition, according to recycling ratio, the remaining portion of the waste is assumed to be incinerated and landfilled at different facilities which are about 40 km and 70 km away from the waste treatment facility respectively. For each scenario, transportation to incineration and landfill facility are considered with differing freight amounts in the loads. Unrecycled portion of the wastes is assumed to be transported with lorries.

The recycling efficiencies and overall electricity consumption shares according to percentage of renewable sources and fossil fuels consumed by the recycling equipment are the main parameters considered in the LCA study. Different recycling efficiencies are applied by considering the residual waste product and its proportional further treatment with incineration and landfilling. The ratio of waste to be incinerated and landfilled is assumed to be decreased as the recycling ratio increases.

In the recycling equipment's electricity consumption of Baseline Scenario – Set 1, it is assumed for coal and natural gas are dominant in overall electricity generation as stated in the Energy Plan (2022), which therefore leads to a recycling process that mainly uses fossil fuels for its electricity requirement. Scenario Set 1 only considers applying the targeted recycling rates of municipal solid waste as proposed in the EU's Waste Framework Directive for the years 2030 and 2035.

Such rate to be achieved in 2050 is assumed considering the country's Net Zero Targets and based on the current targets set for 5-year periods. Modelling of 2030 and 2035 targets show a 5 % increase in the recycling rate; therefore, such value is assumed to reach 80 % for 2050 by applying the same level of increment. Recycling rates and energy share used in this study for Scenario - Set 1 are presented in the following table. It is followed by an example process schematic that belongs to recycling of paper waste.

Table 3.5. Definition of parameters used in Scenario – Set 1

Scenarios	**MSW Recycling Ratio**	**Electricity Generation Profile**
Scenario I 2020	**31.2 %** (euronews, 2021) Combined Fossil Fuel and Renewable Energy fired recycling equipment	Baseline 2020 Scenario - Turkey's National Energy Plan Target Share in Electricity Generation (Fossil Fuel Dominant and Renewable Energy Share)
Scenario II 2030	**60 %** (EU Waste Framework Directive) Combined Fossil Fuel and Renewable Energy fired recycling equipment	
Scenario III 2035	**65 %** (EU Waste Framework Directive) Combined Fossil Fuel and Renewable Energy fired recycling equipment	
Scenario IV 2050	**80 %** (Assumed – Net Zero in 2050) Combined Fossil Fuel and Renewable Energy fired recycling equipment	

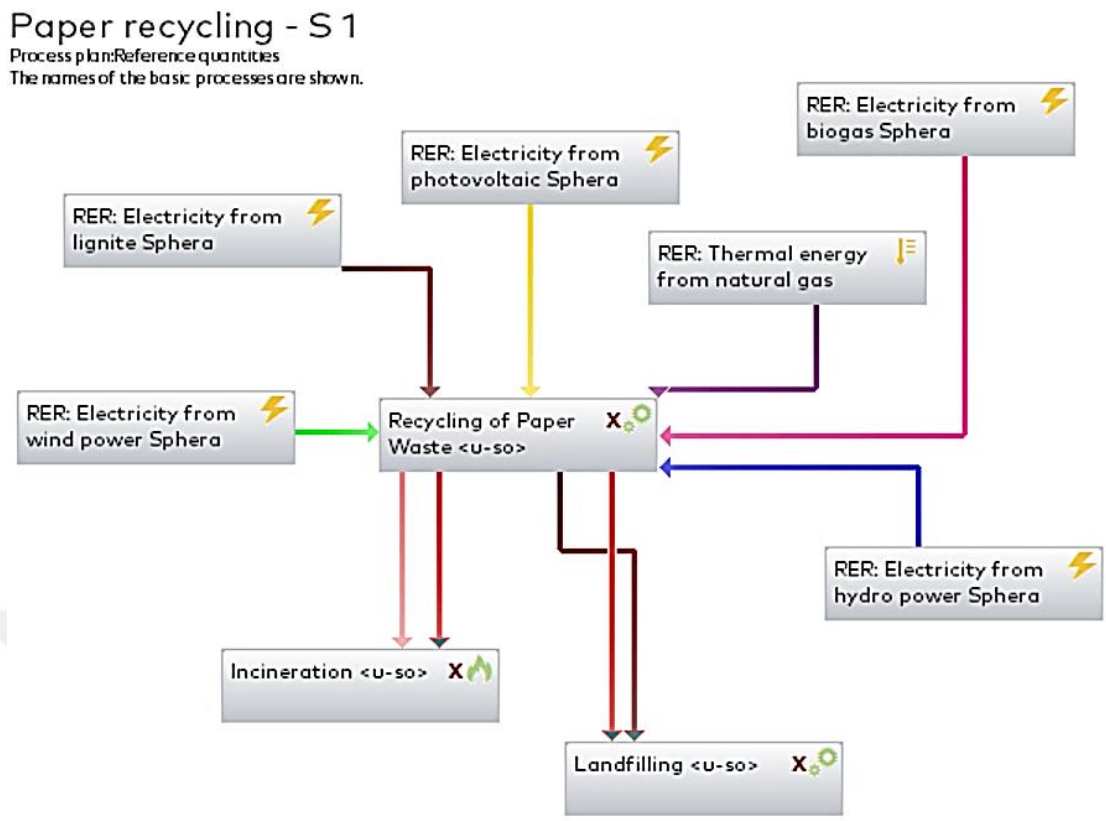


Figure 3.4. Process diagram of recycling paper waste – Scenario I

The study then follows creating a different set of scenarios (Set 2) on the share of electricity sources, which will be consumed by the recycling equipment. The calculations are conducted by integrating current and targeted recycling efficiencies of MSW with differing shares of electricity consumptions as specified below for each scenario. Throughout the entire study, European data for renewable electricity consumption and fuel consumption for transportation are assumed by mainly implementing selections in the processes as “RER: electricity from photovoltaic, wind power, hydro power and biogas” in addition to RER: thermal power.

After baselining calculations, alternative approaches are presented as Scenario 6, 7 and 8, that support the idea of transition to greener and more sustainable practices globally which focuses on reducing the dependency on fossil fuels and aiming to reach net zero in 2050.

Table 3.6. Recycling Rates and Electricity shares used in Scenario V

Scenario V - 2020 (Assumed)

31. 2 % Recycled Content				
Fossil Fuel Share	Solar Power Share	Wind Power Share	Hydropower share	Other (biogas, geo, nuclear)
58 %	4 %	8 %	25 %	5 %

In this regard, Scenario 6 is conducted according to the report of Turkey's Decarbonization Roadmap Net Zero in 2050 published by Istanbul Policy Center (IPC). The report is a comprehensive work covering Turkey's energy profile from many different aspects. The proposed shares of electricity with the recycling rates adjusted for 2030 in Scenario 6 are as follows:

Table 3.7. Recycling Rates and Electricity shares used in Scenario VI

Scenario VI – 2030

60 % Recycled Content				
Fossil Fuel Share	Solar Power Share	Wind Power Share	Hydropower share	Other (biogas, geo, nuclear)
46 %	8 %	11 %	17.5%	17 %

The next Scenario targets the electricity shares introduced in the National Energy Plan of Turkey (2022). For this study the Scenario 7 is constructed aiming to reflect the image with 2035 target rates of shares of solar, wind, hydropower, other renewables and fossil fuels in the overall electricity generation targets of the country, embedded with 2035 recycling rate target.

Table 3.8. Recycling Rates and Electricity shares used in Scenario VII

Scenario VII - 2035

65 % Recycled Content				
Fossil Fuel Share	Solar Power Share	Wind Power Share	Hydropower share	Other (biogas, geo, nuclear)
34 %	16.5 %	18 %	17 %	14 %

Finally, the last scenario (Scenario 8) focuses on the country's Net Zero Targets for 2050. The differing shares in which the generation from renewable energy is dominant over generation from fossil fuels are presented below with an assumed recycling ratio to be achieved in 2050 regarding the previous modelling studies.

Table 3.9. Recycling Rates and Electricity shares used in Scenario VIII

Scenario VIII - 2050

80 % Recycled Content (Assumed)				
Fossil Fuel Share	Solar Power Share	Wind Power Share	Hydropower share	Other (biogas, geo, nuclear)
5 %	46 %	19 %	11 %	18.5 %

In order to implement such scenarios in the GaBi 8.0 software, as input, the electricity shares are proportionally distributed in the flow data of relevant process of each consumer goods' recycling process. The environmental impacts of recycling efficiency are presented by calculating the amount of recycled product and subtracting it from the mass balance which at the end equals to amount of waste that will be sent to incineration and landfilling.

Table 3.10. Overall targeted parameters applied for each scenario in Set 2

		Shares (%)				
Scenario / Year	**Recycling Ratio**	**Fossil Fuel**	**Solar Power**	**Wind Power**	**Hydro Power**	**Other (biogas, geo, nuclear)**
S V - 2020	31	58	4	8	25	5
S VI - 2030	60	46	8	11	17.5	17
S VII - 2035	65	34	16.5	18	17	14
S VIII - 2050	80	5	46	19	11	18.5

The explained methodologies are reflected for each scenario of Set 2 for the recycling process, and an example of plastic packaging waste that illustrates how the recycling rates and electricity shares are distributed in the plans for 2020 (Scenario 5) and 2050 (Scenario 8) are given.

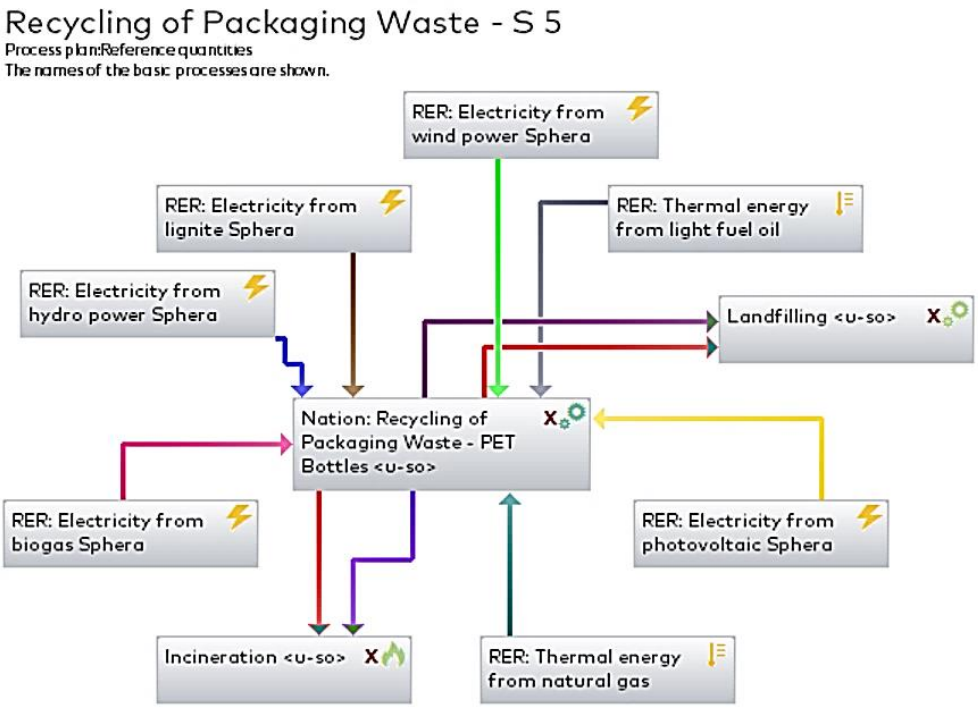


Figure 3.5. Process diagram of recycling plastic packaging waste – Scenario V

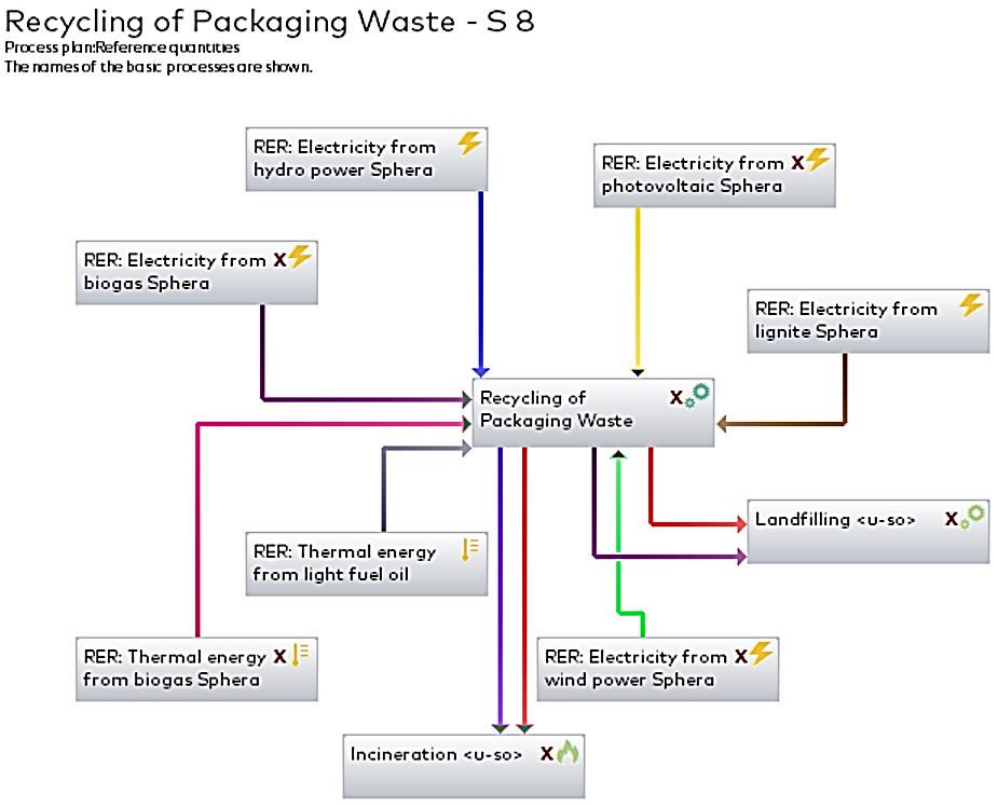


Figure 3.6. Process diagram of recycling plastic packaging waste – Scenario VIII

4. RESULTS AND DISCUSSION

Sustainable consumption and production patterns are analyzed under life cycle assessment perspective in this study. The results are obtained through comparing the environmental impacts when different recycling efficiencies and different shares of renewable electricity are used for the same recycling processes of a FPMIF's household waste. Life Cycle Impact Assessment with the implication of eight different scenarios that represent SCP patterns globally are presented. The impacts of changing consumer behaviour (i.e. increased public awareness in Solid Waste Management) as approached to 2050 is also taken into account.

Among 12 environmental impact categories analyzed in this study according to CML 2001 (August 2016) environmental impact analysis characterization results, the ones that hold highest impact are Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB eq.], Abiotic Depletion (ADP fossil) [MJ], Global Warming Potential (GWP 100 years) [kg CO2 eq.], Human Toxicity Potential (HTP inf.) [kg DCB eq.] and Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.]. Characterization, Normalization and Weighting results are presented in the following figures. Supported with the LCA findings, it is proven that when the share of renewable electricity usage in overall electricity consumption is increased with the increased recycling rates, the environmental impacts become less detrimental. The mentioned impact categories will further be evaluated in detail throughout the study in that manner. Outcomes of the life cycle impact assessment run through different scenario adjustments of Set 1 and Set 2 are presented in the figures below.

For the Scenario – Set 1, the major impact is observed in Global Warming Potential. Remaining impacts did not reflect significant changes however, it is useful to mention the contributors to Photochem. Ozone Creation Potential and Human Toxicity Potential. According to results of the characterization step, the information regarding Scenario - Set 1 will be further presented along with the normalized results.

For Scenario - Set 2, the highest environmental impacts are presented in the figure below which is followed by normalization for both sets. Causes of such impacts are explained in terms of significant processes that contribute to such increases.

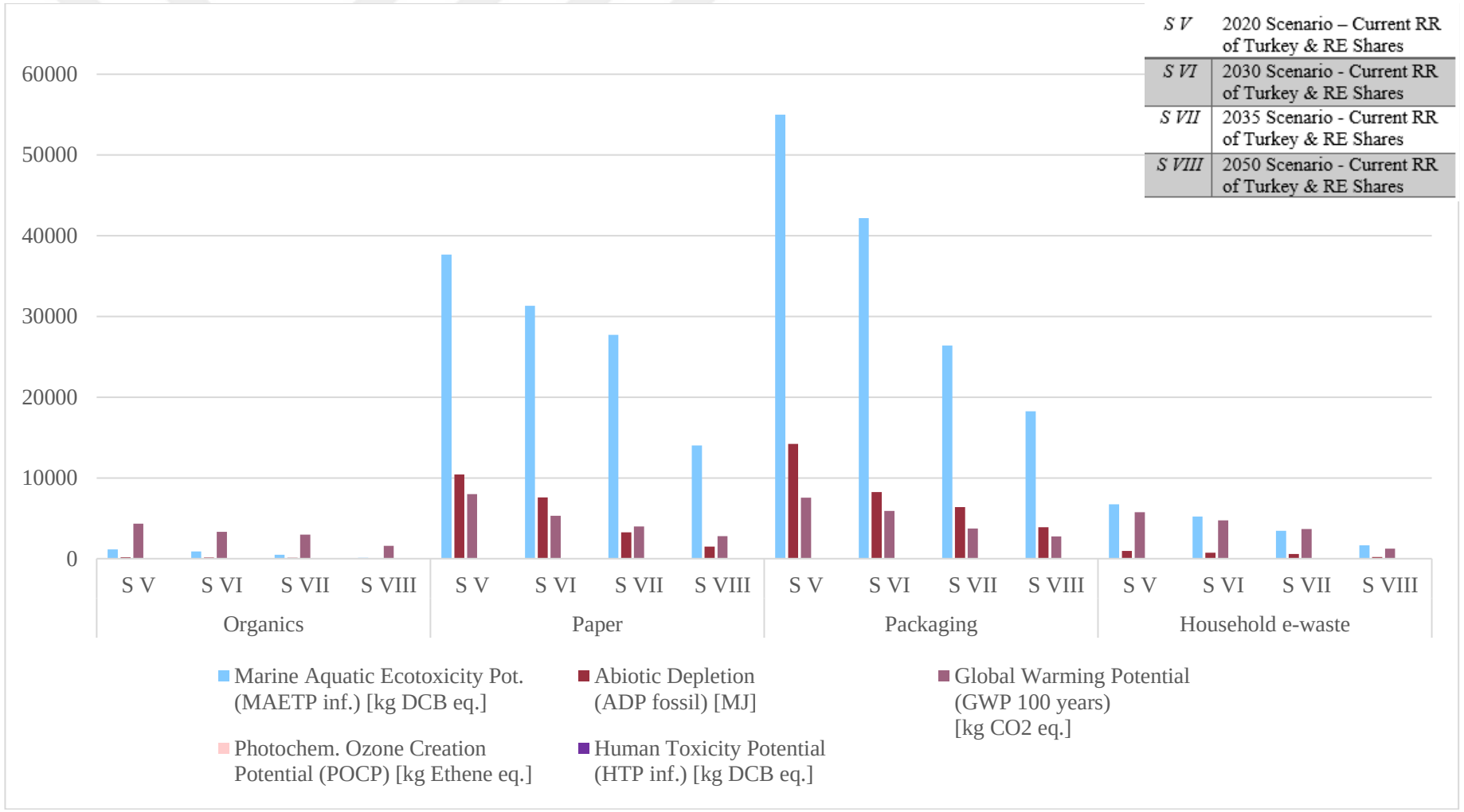
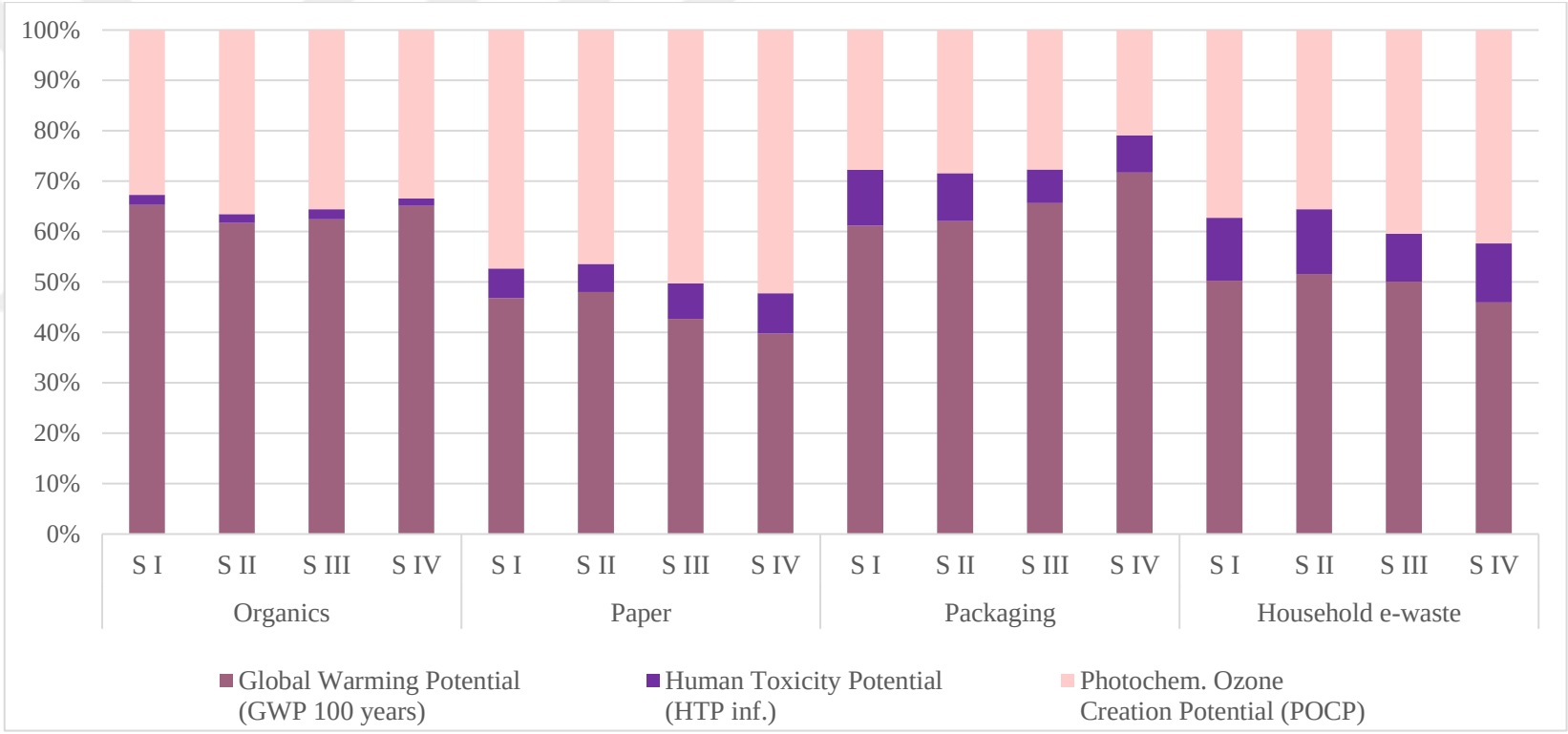


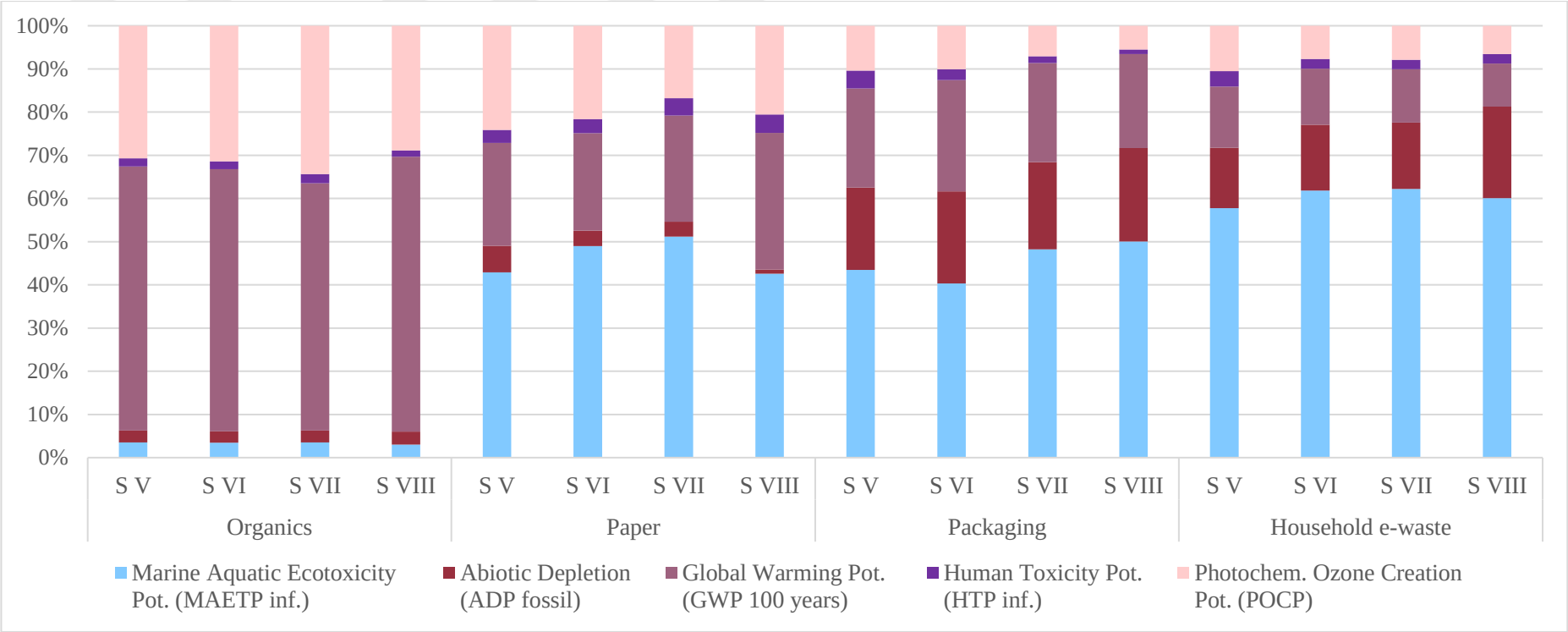
Figure 4.1. Characterization results of 4 different consumer goods waste recycling for Set 2 of Scenarios



S I	2020 Base Scenario – Current Recycling Rate of Turkey & Combined Fossil Fuel and Renewable Energy fired recycling equipment
S II	2030 Scenario of Recycling Rate EU WFD & Combined Fossil Fuel and Renewable Energy fired recycling equipment
S III	2035 Scenario of Recycling Rate EU WFD & Combined Fossil Fuel and Renewable Energy fired recycling equipment
S IV	2050 Scenario Assumed Recycling Rate & Combined Fossil Fuel and Renewable Energy fired recycling equipment

Figure 4.2. Normalization results of 4 different consumer goods waste recycling for Set 1 of Scenarios

As stated before, Scenario Set - 1 is evaluated according to normalized results, but for Scenario Set - 2, the impacts that should be considered are expressed in detail. For Set 1, Global Warming Potential (GWP) and Photochemical Ozone Creation Potential (POCP) are among the major impact categories that should be examined due to a number of facts. The main benefit of recycling is its ability to conserve virgin resources and materials. Recycling avoids the energy-intensive processes of extracting, transporting, and processing raw materials by reusing existing materials. This significantly reduces greenhouse gas emissions associated with these activities, resulting in a much lower GWP score for recycling compared to landfill and incineration. However, landfills produce significant amounts of methane (CH4), a potent greenhouse gas with about 25 times the warming potential of CO_2 over a 100-year period, through the anaerobic decomposition of buried organic matter. This gas escapes into the atmosphere, contributing heavily to a high GWP score of landfilling. Furthermore, leachate may leak from landfills and contaminate groundwater, causing excess methane emissions. In addition to results of landfilling, although incineration recovers some energy from burning waste, it also releases various GHGs directly into the atmosphere, including CO_2, nitrogen oxides (NOx), and CH_4. The exact emissions depend on factors such as incineration technology and waste composition. However, the presence of these potent gases still elevates the GWP score of this method compared to its alternatives. Apart from GWP, deviations are observed in POCP that measures the contribution of different pollutants to the formation of ozone in the lower atmosphere. Ozone is a harmful substance that can cause respiratory problems, crop damage, and climate change. When the waste recycling, incineration and landfilling of waste are the major processes, POCP ranks high because these processes emit various pollutants that have high POCP characterization factors. For example, presence of carbon monoxide (CO), NOx, and volatile organic compounds (VOCs) cause increased results which these pollutants are commonly emitted from waste incineration and landfilling, as well as from transportation and energy consumption associated with waste management. Increased recycling efficiency can reduce these emissions by minimizing the amount of waste that needs to be transported and treated. When the waste is efficiently recycled, it helps minimizing methane emissions and reduces the overall impacts associated with waste disposal by diverting more waste from incineration and landfills.



S V	2020 Base Scenario – Current Recycling Rate of Turkey & Energy Shares according to Turkey's National Energy Plan 2022
S VI	2030 Scenario - Recycling Rate of EU WFD & Energy Shares according to Turkey's Decarbonization Roadmap (Net Zero in 2050)
S VII	2035 Scenario - Recycling Rate of EU WFD & Energy Shares according to Turkey's National Energy Plan 2022
S VIII	2050 Scenario - Assumed Recycling Rate & Energy Shares according to Turkey's Decarbonization Roadmap (Net Zero in 2050)

Figure 4.3. Normalization results of 4 different consumer goods waste recycling for Set 2 of Scenarios

Among studied impact categories, as presented in Figure 4.2 and explained for S1 results, GWP is the one that deviates most when evaluated for the outcomes of anaerobic digestion of food waste (organics) and its further treatment via incineration and landfilling. The results show that along with the recycling process, the incineration and landfilling processes are highly polluting operations when the treated waste is organic waste. Due to high capability of organics' wastes to produce methane and carbon dioxide during incineration and landfilling without recovering, the GWP impact results are too high that have a significant potential to harm the environment through the release of harmful substances.

Most deviations in recycling paper waste are observed in MAETP and GWP. It can be concluded that high MAETP is due to outcomes of recycling itself, electricity consumption from lignite and thermal energy consumption from natural gas, landfilling and incineration. There are a number of reasons to such increase. First, landfill leachate can adversely affect aquatic ecosystems if the landfill is not properly lined or if it leaks, allowing contaminants such as heavy metals, organic pollutants and nutrients to leach into groundwater and eventually reach marine environments. Secondly, incineration emissions can harm marine life, and incomplete incineration can release dioxins, furans, and other persistent organic pollutants that can travel long distances through the air and settle in the oceans. Finally, yet importantly, the recycling process chemicals also have adverse impacts. Although generally less impactful than other options, certain recycling processes, such as those that use chlorine-based bleaching agents, can produce harmful effluents that could potentially harm marine ecosystems if not properly treated. Covering the reasons of high MAETP in paper recycling, high GWP is due to outcomes of recycling itself, thermal energy consumption from lignite and further treatment via incineration and landfilling. The landfilling process itself is a highly polluting operation when the treated waste is paper waste due to high capability of paper wastes to produce methane and carbon dioxide during landfilling similar to organics waste.

Most deviations in recycling packaging waste are observed in MAETP, ADP and GWP. High MAETP is due to outcomes of recycling itself, electricity consumption from lignite and thermal energy consumption from light fuel oil and natural gas, landfilling and incineration. Major contributors to MAETP show a similar pattern as with the paper waste that includes the impacts of landfill leachate, emissions from incineration and chemical leakage to water bodies through rainfalls. High ADP is due to outcomes of electricity consumption from lignite and thermal energy consumption from light fuel oil and natural gas. All processes rely on various forms of energy during processing and transportation, yet recycling uses less energy than others do.

However, it still requires electricity for sorting and recycled plastic production. Incineration uses energy for plant operation and can generate electricity, but it relies on fossil fuels or the grid as backup. Landfills generally require less energy to operate. However, fuel use for transportation can be significant. Packaging recycling may require additional virgin material with embedded fossil fuel energy for blending, depending on the recycling process and the quality of the recycled plastic. If non-renewable energy sources are used and not all of the energy generated is captured, incineration can contribute to fossil fuel depletion.

Most deviations in recycling household e-waste are observed in MAETP and ADP. It can be stated that high MAETP and ADP are due to outcomes of electricity consumption from lignite. Contributors to these impacts show similar patterns as in remaining consumer goods categories.

A must mention impact category is GWP for both sets of scenarios. A high GWP (100-year GWP) indicates that a product, process, or activity is likely to contribute significantly to global warming over a period of a century. This has several critical implications, including an increased warming effect. A substance with a high 100-year GWP traps more heat in the atmosphere than carbon dioxide (CO_2), which is the benchmark gas for GWP. This "radiative forcing" contributes to the increase in global temperatures, which is the driving force behind climate change and can have severe consequences. The 100-year time horizon underscores the long-term nature of the warming effect. Even if emissions of these high-GWP substances cease, their impact on the climate will continue for a century, underscoring the need to act now to mitigate future warming. For all recycling processes, emissions of inorganics to air such as carbon monoxide, sulphur products, nitrogen products, particulates with different sizes cause GWP to increase as well as direct emissions of CO_2 and CH_4.

In the study, the significant outcome is that, for paper, plastic packaging and household e-waste recycling processes, the MAETP levels are quite high when the electricity is dominantly sourced from coal or natural gas for the recycling equipment with a relatively low recycling efficiency. However, when compared to Scenario 7 and Scenario 8 with a high share of renewable source usage, MAETP levels followed a decreasing trend. Lignite and heavy/light fuel oil firing is the major contributor of high MAETP values. Other than emissions to air, emissions to water during paper recycling includes a wide range of polluters such as AOX, Adsorbable Organic Halogen, Chloride, COD (Chemical Oxygen

Demand), BOD (Biological Oxygen Demand) DOC (Dissolved Organic Carbon), Phosphorus, Sulfate, and TOC (Total Organic Carbon) which are present at relatively higher amounts.
Also, for the case of plastic packaging recycling, emissions of Ammonium, Nitrate, Nitrite, Nitrogen organic bound and Phosphorus are among the main polluters that increase MAETP. Nitrate, Nitrite, Nitrogen, organic bound and Phosphorus are also responsible for MAETP to increase when recycling of organics is the case. There were no emissions to water in the process of recycling household e-waste since it is a closed loop machinery system with only an input of electricity and a number of low-effect processes that are not included in the study. However, the amount of electricity required for recycling is relatively high in the household category, therefore lignite, heavy or light fuel firing affect the most.

As another impact category of focus is Abiotic Depletion (ADP Fossil) that ranks high in the overall distribution of studied categories. Turkey relies heavily on fossil fuels for energy, transportation, and various industrial processes. A high ADP Fossil represents that the activity in question is contributing to the depletion of these finite resources, making them less available and potentially more expensive in the future. Among the environmental impacts, high ADP Fossil activities contribute to GHG emissions, exacerbating global warming and its associated problems like extreme weather events, rising sea levels, and biodiversity loss. Another significant outcome to be evaluated is related to plastic packaging and household e-waste recycling processes. The ADP levels are quite high when majority of the electricity is sourced from coal or natural gas. However, when compared to Scenario 7 and Scenario 8 with a high share of renewable source usage, ADP levels followed a decreasing trend. Fossil fuel sources as lignite, oil and natural gas are among the higher contributors to increased levels of ADP.

The percentage changes in LCA results are focused on mentioned environmental impact categories, which hold the highest impact when compared to remaining ones. Five impact categories are analyzed for four different scenarios and comparisons are made as reflected. The percentage changes for the studied environmental impacts that compare results in the years 2020, 2030, 2035 and 2050 are presented in the following table through an example normalization result that belongs to organics/food waste.

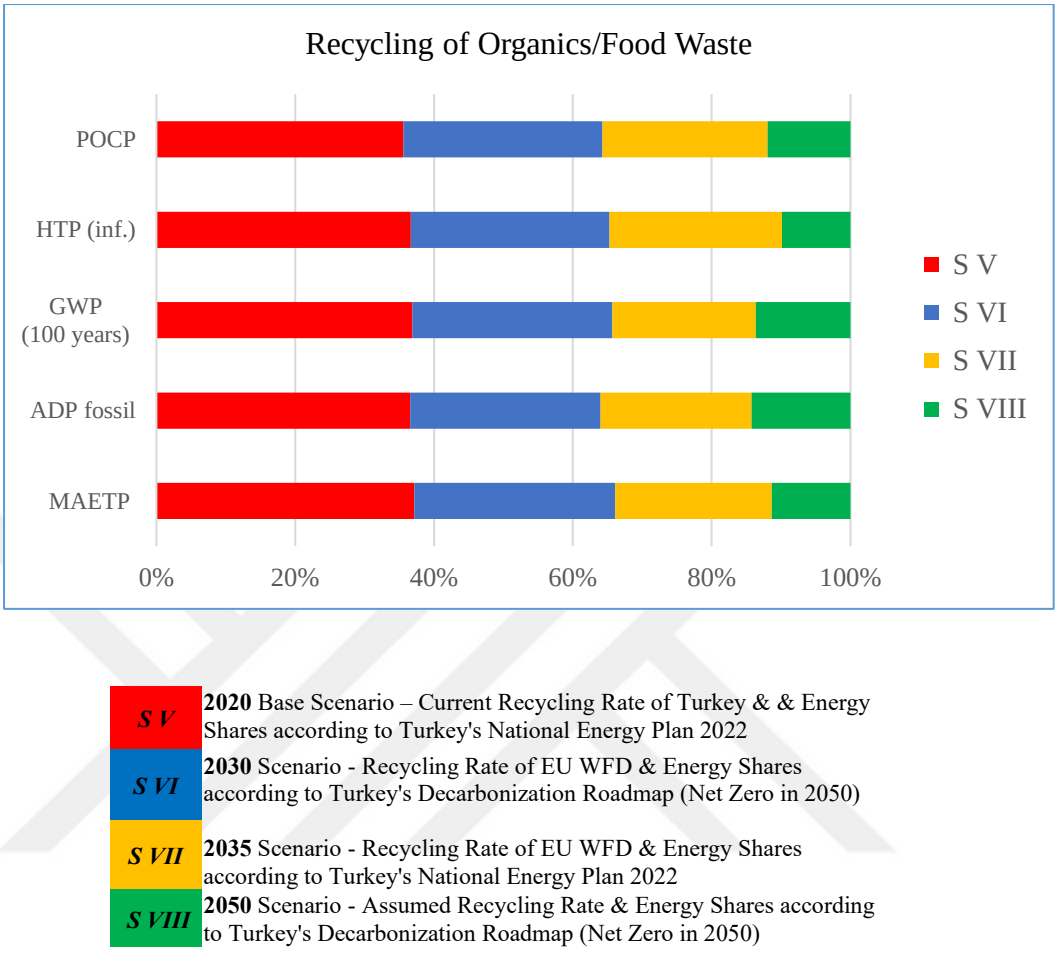


Figure 4.4. Comparison of recycling organics/food waste environmental impacts

Apart from the numerical and graphical results, impact change from 2020 to 2030 (S5 – S6) and 2020 to 2050 (S5 – S8) are compared. Scenario – Set 1 based and Scenario - Set 2 based percentage changes on the outcomes are determined in a way that reflects the change in studied environmental impacts of a FPMIF's waste treatment with the differing parameters in the scenarios.

Table 4. 1. Percentage change (%) in environmental impacts of recycling – Set 1

	Organics (food) waste		**Paper waste**		**Packaging waste**		**H.hold e-waste**	
Environmental Impact	*S I - SII*	*S I – S IV*	*S I - SII*	*S I – S IV*	*S I - SII*	*S I – S IV*	*S I - SII*	*S I – S IV*
GWP (100 years)	-22%	-48%	-10%	-58%	-41%	-44%	-22%	-70%
POCP	-18%	-47%	-14%	-45%	-40%	-64%	-27%	-63%

The changes in impacts are compared as shown in terms of an average FPMIF's waste production that gets recycled with different assumptions on the targeted recycling rates. Percentage changes from S1 to S2 and from S1 to S4 reflect that by only increasing the recycling efficiency of organics (food) waste and paper waste; one can achieve around 15-20% reduction and 50-60% reduction GWP and POCP respectively. For packaging waste and household e-waste, such percentages gather around 20-30% reduction and 50-60% reduction respectively for GWP and POCP.

Table 4. 2. Percentage change (%) of environmental impacts of recycling & electricity mix – Set 2

	Organics (food) waste		**Paper waste**		**Packaging waste**		**H.hold e-waste**	
Environmental Impact	*S V – S VI*	*S V – S VIII*	*S V – S VI*	*S V – S VIII*	*S V – S VI*	*S V – S VIII*	*S V – S VI*	*S V – S VIII*
MAETP	-57%	-89%	-58%	-89%	-53%	-88%	-58%	-91%
ADP fossil	-57%	-91%	-47%	-60%	-56%	-88%	-58%	-94%
GWP (100 years)	-57%	-91%	-56%	-92%	-56%	-85%	-56%	-86%
HTP (inf.)	-57%	-88%	-58%	-93%	-43%	-65%	-50%	-84%
POCP	-58%	-90%	-55%	-88%	-54%	-73%	-52%	-84%

The changes in impacts are compared as shown in terms of an average FPMIF's waste production that gets recycled with different assumptions on the targeted recycling rates and on the targeted electricity generation shares. Percentage changes from S5 to S6 and from S5 to S8 reflect that by increasing the recycling efficiency and the share of renewable electricity during the treatment of organics (food) waste and paper waste; one can achieve around 55% reduction and 80% reduction in all the studied impact categories respectively.

For packaging waste and household e-waste such percentages gather around 55% reduction and 85% reduction respectively. Higher reduction rates are observed for the changes from 2020 to 2050 that supports the importance of renewable energy applications in the light of transition to greener economy and sustainable end of life – recycling practices. The recycling of selected consumer goods is among the energy intensive processes in which the electricity and overall fossil fuel requirement are quite high. Therefore, it is proven by this study that sustainable consumption, end of life treatment methodologies

and greener and resource/energy efficient practices in selected consumer goods have the power of transition to circular and greener economy. After defining and comparing the fundamental environmental impacts of recycling rates and electricity source choices; it is beneficial to introduce how SCP and efficient recycling techniques can be achieved through developing energy and resource efficient applications in each sector.

Undoubtedly, it is not feasible or possible to achieve 100% material and energy efficient applications in a short and limited period as our planet needs to survive and fight against the 1.5 ^{0}C scenario. For example, it is accepted globally that rather than by entirely leaving fossil fuels; only by phasing out from coal or natural gas fired thermal power plants for electricity generation is an applicable practice. However, reducing the share of such polluter fuels will not only result in reducing the GHG emissions, but also will lead to reduced ecotoxicities causing deterioration of the Earth's systems which are the main drivers of a stable and livable environment. The share of using fossil fuels for energy needs can be reduced by many ways. Investing in renewable energy sources more such as solar, wind, and geothermal power is crucial for reducing the dependency on fossil fuels and mitigating climate change. Additionally, improving energy efficiency and electrification applications sourced by renewables can help reduce the overall demand for fossil fuels while maintaining the current level of economic activity. Regarding the Climate Target Plan of EU that focuses on reduction of greenhouse gas emissions to at least 55%, a number of energy and resource or'ented initiatives have been proposed to maintain the target such as - EU Chemicals Strategy for Sustainability, EU Renovation Wave Strategy and EU Methane Strategy - October 14th, 2020. (European Commission[8 a,b,c])

To achieve sustainable waste management, a country could invest more in modern waste management infrastructure such as recycling, composting and energy recovery facilities to reduce landfill waste. (Okedu et al. 2022) From the financial perspective, promoting green finance and investment can mobilize capital for sustainable projects. The country can provide incentives for green investment, develop green finance mechanisms such as green bonds, and establish partnerships with international organizations and investors to fund green initiatives. (UNEP, n.d.) Promoting sustainable agricultural practices such as encouraging agroforestry and helping rural communities transition to renewable energy sources for agricultural activities may also help reduce emissions and preserve nature. Turkey should implement policies to preserve its natural forests and promote sustainable forest management practices.

The protection of existing forests, the fight against deforestation, and the implementation of afforestation and reforestation efforts can help to sequester carbon dioxide from the atmosphere (Marchi et al. 2018).

In addition to these, Turkey could provide incentives for the separation of recyclable materials, implement extended producer responsibility programs, and promote the use of recycled materials in household manufacturing processes to ensure efficient household waste management. Also, initiatives such as community composting programs, neighborhood clean-up campaigns, and zero waste practices can be promoted. From a governance perspective, effective measures to promote energy efficiency which include the provision of tax incentives for energy-efficient appliances and the promotion of environmentally friendly products through labeling programs could be applied (Jonkutė & Staniškis, 2016).

International cooperation and knowledge sharing are crucial for the adoption of best practices in waste management and sustainable consumption, given Turkey's geopolitical location and its role as a bridge between Europe and Asia. In order to achieve environmental sustainability goals, Turkey can cooperate with international organizations, neighboring countries, and global partners in the exchange of expertise, technology, and resources. The country can use its diplomatic relations to foster regional cooperation on environmental issues through the promotion of dialogue and cooperation with neighboring countries. In addition, Turkey can promote research and development in areas such as the automation of waste sorting, advanced recycling technologies, carbon capture and storage technologies, and sustainable packaging solutions in order to optimize the use of resources and minimize the impact on the environment (Akçalı et al. 2023).

4.1. Efficiency in Organics/Food Waste Recycling

Current techniques include composting and anaerobic digestion (AD) for recycling organic matter. There are types such as home composting, community composting and in-vessel composting for regular composting methods, where for anaerobic digestion it is mainly focused on microorganism activity in digesters where break down of organic matter occurs in the absence of oxygen and production of biogas (methane) used for electricity or heat generation. Hydrothermal carbonization, which converts organic

waste into biochar, a stable carbon source for soil amendment or fuel production, should not be underestimated as a relatively more sustainable application.

Similar to the efforts presented in the study for other consumer products, preventing the generation of organic waste is one of the key solutions. The use of clear labeling on food packaging to raise awareness of the consequences of food waste and promote responsible food handling practices are examples of ways to reduce household food waste. In order to minimize food waste at the household level, effective meal planning, proper portioning techniques, and creative use of leftovers are alternative practices that should be adopted (Sridhar et al. 2021).

The promotion and facilitation of home composting through readily available bins, educational materials and community composting facilities is essential to food waste reduction. Such applications convert organic waste into valuable compost for gardens and agriculture, which is also an economically beneficial application for industrial and municipal expenditures. Investment in large-scale facilities equipped with anaerobic digesters also contributes to economic savings for industry, which also results in reduced greenhouse gas emissions through microbial activity. These digesters break down organic matter, producing biogas (methane) that can be used to generate electricity or heat, resulting in reduced fossil fuel consumption (Babu et al. 2021).

Whether through home food waste compost, or through the implementation of disposal fees or tax breaks for compost and biogas, collective efforts can greatly improve the energy efficiency of food waste and organic recycling, promote soil health, and create valuable resources such as compost and biogas (Slorach et al. 2019).

4.2. Efficiency in Paper Recycling

Compared to making paper from virgin pulp, paper recycling is an effective way to save energy. Traditionally, paper is recycled by mechanical recycling, cleaning, deinking, blending and papermaking as the final step. Another method is chemical recycling, which involves depolymerization using chemicals or heat. Both techniques have limitations and environmental impacts. Chemical recycling is often complex and expensive, while mechanical recycling requires significant energy and water. In

addition, contamination with non-paper materials can disrupt the process and result in rejected batches that end up in landfills (Simão et al. 2018).

Leaving behind the traditional techniques; there are ways to further improve the efficiency of paper recycling. One such way is the reduction of contamination levels through public education. Clearly labeling what is and is not recyclable in local recycling programs is important. This reduces the risk of contamination, which could lead to whole batches being rejected for landfill. Investing in optical sorting equipment and other technologies that can efficiently separate different types of paper and remove contaminants is recommended to improve sorting (Del Rio et al. 2022).

The recycling process can also be improved by optimizing collection and transportation routes. Multi-functional software can be used to plan efficient collection routes for recycling trucks, which can reduce fuel consumption and emissions. Businesses and institutions should be encouraged to generate large volumes of paper waste for less frequent collection to further reduce the number of truck trips required. Another suggestion is to improve overall processing efficiency. In order to modernize the pulping and papermaking equipment, it is recommended that investments be made in energy-efficient machines that use less water and electricity to process the recycled paper pulp. Water and energy consumption can be reduced by exploring less energy-intensive pulping methods, such as dry pulping. As the share of dry pulping applications in the conventional recycling process increases, the paper industry will use fewer resources.

Finally, not all responsibility lies with the manufacturer, as discussed earlier. Promoting paperless options for invoices, receipts and other documents is recommended to reduce overall paper consumption. It is also a good practice to support initiatives that encourage the use of digital communications and document management. When purchasing paper products, it is wiser to choose those with recycled content to close the loop and reduce demand for virgin pulp. In connection with the choice of paper category, it is important to be aware that the efficient recycling of different types of paper, including products that are difficult to recycle, such as coated papers and glossy magazines, requires investment in research into new technologies. It is also important to consider bio-based alternatives to traditional paper, made from sustainable, rapidly growing plants like bamboo and hemp that require fewer processing steps and are more environmentally friendly (Lipiäinen et al. 2022).

4.3. Efficiency in Plastic Packaging Recycling

Mechanical recycling, chemical recycling, and energy recovery applications are the most popular traditional plastic packaging recycling techniques. However, these processes have several negative environmental impacts. Mixed and contaminated plastic streams complicate sorting, leading to inefficiencies, contamination, rejections, and reduced recycling rates. The main aim of the study is to highlight that both mechanical and chemical recycling of plastic packaging require significant energy, which contributes to increased levels of greenhouse gas emissions. Furthermore, plastic packaging recycling often results in downcycling, where the recycled plastic is turned into lower-quality products that may require further recycling in the future. In addition, the recycling process can result in the leaching of chemical additives during the polymerization process. Some additives in plastics can be harmful if not properly removed during the recycling process and can potentially leach into the environment. Lastly, it is important to note that plastic packaging recycling has a limited scope, as not all plastic types are easily recyclable. This can result in some plastics ending up in landfills or being incinerated without energy recovery (Ragonnaud, 2023).

Despite the environmental challenges, there are several ways to increase the efficiency of plastic packaging recycling. One way is through the modernization of recycling facilities with greener forms of plastics recycling equipment and processes. Key solutions include replacing equipment with more energy-efficient machines that use less water and electricity for sorting, cleaning, and processing. Companies can invest in high-efficiency motors, improved insulation, and automated systems to promote sustainability. For complex packaging materials, such as food-contaminated containers or multi-material bags that are currently difficult to recycle, they can research and develop innovative technologies. This could involve using enzymatic deconstruction processes or dedicated recycling lines for certain materials. It is also important for manufacturers to promote sustainable packaging design. Encouraging and incentivizing the use of packaging with a high percentage of recycled materials is crucial. This can include providing tax breaks to manufacturers who use recycled content or awareness campaigns to educate consumers about the benefits of doing so, such as promoting Deposit Refund Schemes. Additionally, the technique of “Design for Easy Recycling” can be effective. Manufacturers should be encouraged to design packaging that is easy to disassemble and made of materials compatible with existing recycling processes. This can be achieved through the use of standardized materials, the

avoidance of glued or bonded components and the use of closures that can be easily separated (Schaefer and Cheung, 2018).

Another option is to reduce packaging. It is important to avoid excessive packaging whenever possible. Encouraging the use of refillable or reusable containers, promoting concentrated formulations for home care and hygiene products, and designing products that require less protective packaging are all ways to promote minimal packaging.

In the realm of research and development, it is crucial to investigate bio-based alternatives and invest in sustainable, fast-growing packaging materials, such as bamboo or mycelium, similar to paper recycling. These materials require less processing and have a lower environmental impact compared to traditional materials (Du Rietz and A. Kreme, 2023).

4.4. Efficiency in Household E-Waste Recycling

E-waste recycling involves several stages, each employing specific techniques. The first step is the collection and pre-processing. Municipal drop-off centers, retailer take-back programs, and specialized e-waste collection services ensure proper handling for collection systems. Sorting and dismantling are the next step in e-waste management. After sorted and dismantled, waste is further processed for material recovery. Magnetic separation, eddy current separation and hydrometallurgy techniques are applied to recover precious materials.

As determined by the waste hierarchy and suggested for each sector in this study, reducing e-waste generation is key to achieving efficiency in both energy and resource usage. There are many ways to handle e-waste, including alternatives starting from the production stage. One of these alternatives is extending product lifespans, which encourages repair and refurbishment programs for electronics. This encourages responsible consumer behavior and delays the need for replacement. It reduces the overall generation of e-waste. Another technique is designing for durability and repairability.
This advocates that manufacturers prioritize stronger materials, modular designs, and readily available spare parts in their products. This eases the repair process and prolongs the life of the equipment (Yıldırım, 2023).

Once waste is generated, it is critical to optimize its collection and processing. By investing in advanced sorting technologies, it is possible to efficiently separate the materials within e-waste and minimize the energy required for subsequent processing steps. After e-waste is separated into its valuable sub-products, implementing innovative dismantling methods that require less energy and generate fewer harmful emissions can result in decreased negative impacts on the environment. Toxic heavy metals, ferrous and nonferrous materials, and some refrigerants have the potential to be emitted into soil, water, or air, increasing toxicity in these ecosystems.

Efficient recycling can be achieved by promoting the use of advanced recycling technologies, such as investing in greener and more energy-efficient methods for extracting valuable materials from e-waste, such as hydrometallurgy or bio-leaching processes. Additionally, resource efficiency during recycling can be improved by reducing water and chemical usage during the process. Developing recycling processes that require minimal water and harmful chemicals can minimize environmental impacts and energy consumption. Closed-loop systems for water and chemical reuse can prevent possible chemical leakages, such as refrigerant gases required to cool down the recycling equipment (Forti et al. 2020).

From the consumer perspective, as highlighted in the study promoting responsible consumer choices counts for a big step. Starting with the support of manufacturers using recycled materials, it is essential to encourage purchasing electronics made with significant recycled content. This closes the loop on resource utilization and reduces demand for virgin materials, requiring less energy for extraction and processing (Barapatre and Rastogi, 2022).

4.5. Material Recovery and Recyclable Materials

In July 2014, a legislative proposal was adopted to renew recycling and waste-related targets in the WFD, the Landfill Directive (1999/31/EC), and the PPWD (94/62/EC). The proposal includes an increase in the recycling rate of municipal waste to 70% by 2030, an increase in the recycling rate of packaging waste to 80% by 2030 with specific material targets, and the phasing out of landfilling of untreated municipal waste.

Recovery of recyclables from waste has been approached in two ways; first source separation and separate collection systems at individual households, and second, mechanical processing and sorting of

mixed residual waste at centralized facilities receiving larger waste streams. Despite efforts to develop specific technology, the quality of the output product proved inadequate for existing recycling operations, with the risk of releasing hazardous substances into the environment, such as heavy metals. As a result, and strongly reflected in current European waste legislation, source separation and separate collection are now considered the more technically and environmentally feasible approach.

In many European countries, recyclable materials are often found in residual or mixed municipal solid waste streams. This is due to poorly performing separate collection systems or the lack of such systems. However, in recent years there have been more examples of highly automated facilities. These facilities use advanced process flows and specialized sorting technology to recover recyclable materials. Recyclable materials, including plastics and metals, are recovered from residual MSW in some parts of Europe and North America, complementing source separation schemes. Central sorting is expected to play an even greater role in the future due to increasing materials complexity, fast urbanization, and growing global demand for secondary raw materials (Cimpan et al. 2015).

Approximately 70% of collected MSW ends up in landfills, 19% is recycled, and 11% is used for energy recovery. Regarding these facts, it is crucial to mention that effective management of MSW falls under two of the UN SDGs: Goal 12 (Responsible Consumption and Production) and Goal 11 (Sustainable Cities and Communities). However, diverting MSW for Waste-to-Energy (WTE) conversion can also help achieve Goal 7: Affordable and Clean Energy. Municipal solid waste is a valuable, renewable and economic waste resource that can be used to recover usable solid, liquid and gaseous fuels to help meet the growing demand for energy (Nanda & Berruti, 2021).

Food waste, paper, PVC, PET, and plastic bags and films can be recycled through energy and material recovery. According to Chen & Chen's (2013) analysis the selection of the optimal waste treatment method hinges on a confluence of factors, including the energy conversion efficiency of Waste-to-Energy (WTE) facilities, carbon pricing schemes, electricity tariffs, and the economic viability of material recovery. The analysis suggests that WTE facilities that forego sorting and recycling processes may be favored under conditions of high energy recovery efficiency and low carbon taxes. Conversely, for facilities with lower efficiency and in regions with high carbon taxes, emphasis may shift towards relevant recycling technologies (material recovery). This implies that waste fractions with high calorific value can be beneficially utilized as fuel sources for electricity generation in WTE plants.

This study highlighted the importance of recycling, yet there exists a number of efficient methodologies to achieve SCP patterns. Considering the energy recovery efficiency of WTE facilities and the pollution costs (carbon taxes), it may not be cost-effective to recycle all materials. Some waste fractions with high heating value may be better suited for energy recovery methods, which can be an environmentally friendly processing option. The line between material recovery and energy recovery processes is not always clear. Overall, the incorporation of recycling and energy recovery into waste management practices can provide advantages such as conserving NRs, extending the lifespan of disposal sites, and reducing secondary pollution (Chen & Chen, 2013).

Even though choosing alternatives that promote material recovery or increased recycling efficiencies, it is well-known that raising awareness and changing consumer behaviour are among the key challenges in transition to CE. Such developments can only be achieved by the implementation of sustainable SWM practices which promote introducing regulatory frameworks, economic incentives, and public education programs about recycling efforts. A number of strategies that should be followed to achieve SCP in public are listed as follows:

- Governments would implement stringent laws and policies, including mandatory separate collection systems and waste sorting at the household level.
- To increase recycling efforts, education and outreach programs are critical. Residents' attitudes and behaviors can be changed by providing them with knowledge about recycling.
- Individuals can be encouraged to recycle more by presenting recycling as a desirable social trend and emphasizing social norms.
- A variety of incentive schemes to encourage recycling practices would be offered, such as deposit refund schemes and pay-as-you-throw schemes (Knickmeyer, 2020).

5. CONCLUSION

The Sustainable Consumption and Production (SCP) patterns in Turkey are examined with a need driven by concerns about excess resource depletion and ecological instability due to population growth urbanization and industrialization. The importance of promoting sustainability and green practices in all facets of life, from short-term consumables like food, paper and packaging to long-term products like household electrical equipment, with a focus on sustainable end-of-life practices are introduced with a Life Cycle Assessment perspective. The study aligns the SCP concept with the National Energy Plan, 2022, Decarbonization Roadmap of Turkey and the EU Waste Framework Directive along with the EU Circular Economy Action Plan. The crucial role of transition to a greener economy is highlighted with several proposed initiatives that suggest producers, consumers, government, stakeholders and NGOs to take action.

By leveraging the proposed strategies, such as increasing the recycling efficiencies and share of renewables in electricity generation, significant reductions in environmental impacts can be achieved. Results of life cycle assessments have shown that decreasing the amount of waste sent to incineration and landfills and increasing the share of renewables in the country's overall electricity production by the years 2030, 2035 and 2050 can significantly reduce emissions to air, water and soil as well as extraction and consumption of resources resulted from waste management operations. In conclusion, it is targeted to prove that by increasing the efficiency in waste recycling and decreasing the consumption of fossil fuels and promoting renewable electricity, the intensity of adverse environmental impacts shows considerable reductions which support the fact that transition to green economy in almost each aspect of our lives is a crucial concept.

From raw material extraction to use phase, there are numerous possible solutions to decrease such impacts which promote the SCP patterns. However, from electricity consumption perspective in the life cycle – end of life of a product, the negative effects of these fossil fuels carry a great number of impacts that are to be considered separately. Therefore, this study emphasizes the need for a collective effort to adopt sustainable consumption and production principles that align with national and international resource, energy and environmental strategies.

Results are presented by conducting a detailed Literature Review on SCP and by consolidating recycling inventory data on selected sectors which are accessed (i) through up-to-date literature search/findings, (ii) through scientific datasets obtained from the GaBi 8.0 database and Ecoinvent database, and (iii) from an integrated waste management company (Company A) located in Tuzla, Istanbul, Turkey. Sectors subjected to this study include food (organics) waste, paper waste, packaging waste and household e-waste. The results are presented and compared by focusing on five environmental impact categories of the LCA study conducted through CML 2001. The ones that contribute the most to the results are the Marine Aquatic Ecotoxicity Pot. (MAETP inf.) [kg DCB eq.], Abiotic Depletion (ADP fossil) [MJ], Global Warming Potential (GWP 100 years), Human Toxicity Potential (HTP inf.) [kg DCB eq.] and Photochem. Ozone Creation Potential (POCP) [kg Ethene eq.].

Output data of the study provided that firing of lignite, heavy/light fuel oil natural gas and thermal energy from fossils are among the major contributors of high MAETP and ADP and methane and carbon dioxide emissions during incineration and landfilling activities are among the major contributors of GWP.

For Scenario Set 1, the changes in impacts are compared in terms of an average FPMIF's waste production that gets recycled with different assumptions on the targeted recycling rates. Percentage changes in the environmental impacts from S1 to S2 and from S1 to S4 reflect that by only increasing the recycling efficiency of organics (food) waste and paper waste; one can achieve around 15-20% reduction in GWP and 50-60% reduction in POCP. For packaging waste and household e-waste, such percentages gather around 20-30% in GWP and 50-60% reduction in POCP. For Scenario Set 2, the changes in impacts are compared in terms of an average FPMIF's waste production that gets recycled with different assumptions on the targeted recycling rates and on the targeted electricity generation shares. Percentage changes from S5 to S6 and from S5 to S8 reflect that by increasing the recycling efficiency and the share of renewable electricity during the treatment of organics (food) waste and paper waste; one can achieve around 55% reduction and 80% reduction in all the studied impact categories respectively. For packaging waste and household e-waste such percentages gather around 55% reduction and 85% reduction respectively.

Higher reduction rates are observed for the changes from 2020 to 2050 that supports the importance of renewable energy applications in the light of transition to greener economy and sustainable end of life – recycling practices. The recycling of selected consumer goods is among the energy-intensive processes in which the electricity and overall fossil fuel requirements are quite high.

Emissions to water and air are in significant levels and complexity during paper and plastic packaging recycling when compared to other consumer goods. The effects of incineration and landfilling of organics and paper that were significant due to potential methane and carbon dioxide emissions during disposal are presented and further compared. According to decreased impacts when higher recycling rates are achieved and higher share of renewables is used for electricity consumption; potential for significant environmental benefits, such as reduced greenhouse gas emissions and reduced resource depletion and water and air pollutions are highlighted in the study. The conclusion is also customized to include specific recommendations based on the study findings or possible energy and resource efficient suggestions that can be tailored to a particular audience. Efficient recycling techniques are discussed that mainly aim to close the product's life cycle loop and positively contribute to circular economy by promoting greener alternatives. It is observed that increasing public awareness on waste handling both from manufacturer and consumer perspective is vital to mitigate the impacts of climate change.

Even though waste management mainly promotes the minimization of waste production, this study covers alternatives regarding treatment efficiencies of the waste produced from a bioeconomic and energy efficient technological perspective. The study proves the numerical results by reflecting the current situation in Turkey with traditional recycling techniques applied over household waste and when the share of renewable energy sources in the country's electricity generation profile is increased to target levels; together with increased recycling efficiencies which favor the percentage of incinerated and landfilled waste to decrease.

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